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# PHYSICAL GEOGRAPHY

IN ITS RELATION TO THE

# PREVAILING WINDS AND CURRENTS.

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BY

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# PREFACE.

THE study of the nature, character, and effect of the prevailing winds of a country, and of the currents which wash its shores, is as much a part of its geography as is that of the outline of its coasts, or of the contour of its mountains. In its widest extent it not only brings us face to face with the ever fresh phenomena of Nature, and leads us to a closer acquaintance with the secrets of her power, but it sets forth much that is soundly and practically useful to the seaman. It has thus been fully recognised as a branch of geographical science not only by the Royal Geographical Society but by the Admiralty, although by a curious contradiction it has hitherto been assigned, almost exclusively, to Meteorology, or rather to that particular division of Meteorology which treats of the hydrostatic condition of the Atmosphere and the Ocean.

Meteorology of course forms a very important part of all questions that relate to the movements of the air; the differences and variations in density, elastic force, temperature or humidity, must at all times exercise a very great influence on the relative equilibrium of atmospheric masses; but the difficulty which confessedly overlies the

whole subject seems to me due, in part at least, to the positive way in which it has so generally been assumed that these hydrostatic fluctuations are the *sole* causes of all atmospheric motion; due, in fact, to the want of a clear understanding of the distinction and connection between Meteorology and Geography.

To illustrate this distinction and this connection, I have devoted a considerable portion of the following pages; but a still larger portion is devoted to a detailed and analytical account of the phenomena referred to, and to an attempt to trace them back to their natural causes, whether those causes are geographical, meteorological, or cosmical. In doing so, I have adopted a method which, though it differs essentially from that which has of late years been very generally followed, is, I would submit, both more exact and more scientific. I have endeavoured to explain the phenomena which are observed, rather than to observe phenomena in illustration of theoretical views. There is no more dangerous source of error in physical science than a strong conviction that certain phenomena must exist, and a determination to find them. Difficult as it is to banish from the mind all preconceived ideas, and to inquire into things as they really are, not as they have been imagined to be, it is only by such a beginning that we can hope to arrive at a knowledge and understanding of the truth.

But the fact is, we are at all times in too great a hurry to generalize; we are too fond of repeating that Newton worked out the great idea of universal gravitation by generalizing from the fall of an apple: perhaps he

did; but we are not Newtons, and might occasionally do well to remember that even a donkey—according to Mr. Lowe—generalizes on the obnoxious nature of wheel-barrows. Generalization is necessary for scientific classification; it is necessary for a right understanding of the phenomena classified; it is necessary, if only as an aid to memory; but a hasty generalization is, in all probability, a false one, and—founded on imperfect and incorrect data—leads to results on which no confidence whatever can be placed.

The work which I have undertaken would evidently not be complete without generalization: without generalization, it would have been impossible for me to attempt anything like a systematic explanation of my subject, or to enter into the important question of cause: but to that generalization I have been guided by thousands and thousands of independent and detailed observations, careless of any theory to which it and they might conduct me.

Thus, entering on the subject from a different starting point, and travelling by a different road from that taken by my more immediate predecessors, the results of my inquiry are also, in many cases, very different. In the body of the work I have had to call frequent attention to the main points of this difference; for though I have endeavoured, as much as possible, to avoid what might be mistaken for controversial display, opinions, supported by the weight of many years general acceptance, and by the writings of many distinguished meteorologists, are not lightly to be set aside.

But whether the conclusions I have formed are right or wrong, there cannot I conceive be any doubt as to the correctness of the method I have adopted. It is the method which has been adopted in every branch of science—except this—and often with the most astounding success: it is the method which has led to every advance in science during the last three hundred years, from the time of Kepler down to the present day. The method is not answerable for any mistakes I may have made: whoever or whatever is wrong, it is right.

By analysis of facts and observations I have been led to my conclusions; on these facts, these observations, the whole work is founded; and to establish that foundation on a firmer basis, I have given numerous references to the printed sources of my information; to the many opportunities I have had of acquainting myself with the personal experience of messmates and friends, in almost every part of the world, I cannot more directly refer. I can only acknowledge the assistance so readily given me by the Officers of the Hydrographic department of the Admiralty, and more especially by Staff-Captain Evans and Staff-Commander Hull, which has enabled me to make the practical part of my work, and particularly the chapter on Currents, more complete than I could otherwise have hoped to do.

ROYAL NAVAL COLLEGE,
*May*, 1870.

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# PHYSICAL GEOGRAPHY

IN ITS RELATION TO

# THE PREVAILING WINDS AND CURRENTS.

## CHAPTER I.

### THE PREVAILING WINDS.

### SECTION I.

THE GEOGRAPHICAL DIVISION OF THE ATMOSPHERE.

AIR is the invisible elastic fluid, which lies over the surface of the earth, completely surrounding the globe and enveloping everything upon it.

The fact that air is a compound gas, consisting of oxygen and nitrogen in a nearly uniform ratio of 1 to 4, is to us, entering on the study of that branch of Physical Geography which treats of the movements of air, important principally as showing that between different localities and different heights above the earth's surface there must be a continual interchange. The thorough intermixture and the approximate uniformity in the proportion of the two constituent gases, everywhere observed, has frequently been considered as necessarily due to an actual shaking together, and as therefore proving a very constant mechanical movement of volumes of air from place to place.

That such movements are going on, almost without cessation, is familiar to us all: that they produce results in the highest degree important is unquestionable; but it

is equally unquestionable that the intimate and uniform mixture of the components of air is the necessary condition of two gases left in free contact for a long time. It is due to the peculiar relation between the elastic forces of different gases, by virtue of which any one gas expands itself into the space occupied by another, as into a vacuum.

This property, which seems absolutely opposed to hydrostatic theory, is capable of very satisfactory experimental proof. If a bottle, filled with hydrogen, the lightest of known gases, be inverted over a bottle filled with carbonic acid gas, one of the heaviest, a free communication being left between the two, the carbonic acid gas will gradually disperse itself through the upper bottle, the hydrogen will gradually creep down into the lower; and at the end of a few days the two bottles will be found to contain a common mixture of nearly equal parts of the two gases.

We can readily understand how the elastic force of either of these gases would cause it to swell out and fill the other bottle, were that other bottle empty; but the exact manner in which it causes each of them to swell out against an elastic force equal to its own has not yet been ascertained; it is, nevertheless, thoroughly established that, except in point of time, the pressure of one gas does not affect the expansion of another. Its effect in retarding the expansion is great; but in the constitution of the atmosphere, time—whether days, years, or centuries—cannot be a matter for consideration.

This slow, imperceptible motion of the particles of air amongst each other is thus of a nature entirely different from that more violent motion of large volumes, which is called WIND, the causes and effects of which form, to a great extent, the subject of the following pages. I have mentioned it here because I conceive that it has been overlooked by many writers, who have, therefore, attributed its results to some direct mechanical agency, and have main-

tained, from the outset, that air, as a sensible current, is continually circulating over the face of the globe; every small volume of it being successively carried by this circulation to every part of the world and to every possible altitude above it. How far there really is such a circulation is a legitimate subject for inquiry: its existence, and the extent to which it prevails, may, perhaps, be proved by evidence of a more direct nature; but the uniform composition of the atmosphere cannot be accepted as establishing a fact to which, as familiar chemical laws assure us, it bears no necessary relationship.

We are thus compelled, before proceeding further, to form within our minds a distinct conception of what is to be understood by the word WIND. It is commonly defined to be air in motion; but such a definition is imperfect, for air may be, and constantly is, in motion without there being any wind. It must be well known to all of us that, for instance, in a warm room, the air is moving with great regularity, but there is no wind: that on a warm, sultry day small bodies of air are wandering in every direction: that on a clear frosty night a satisfactory astronomical observation is almost out of the question, on account of the fine streaks of air which keep rising and falling like the streaks of water in a boiling pot, and which can be seen through a strongly magnifying telescope, though they cannot be felt. These are all examples of air in motion; but they are not wind.

WIND I would, therefore, define to be air in sensible motion—that is, moving with a perceptible velocity in a direction parallel, or nearly parallel, to the surface of the earth. The Beaufort Scale, now adopted by all English seamen, and in very many meteorological reports, may be considered as explaining and illustrating this definition in the ordinary, and especially in the nautical, acceptation of the word.

| Beaufort Scale of relative force. | Explanation as given by the Admiralty. | | | Estimated Velocity of the wind in miles per hour. |
|---|---|---|---|---|
| 0 | Calm | | | 0 |
| 1 | Light air, just sufficient to give steerage way | | | 2 |
| 2 | Light breeze | with which a well-conditioned man-of-war, under all sail and clean full, would go in smooth water from | 1 to 2 knots | 4 |
| 3 | Gentle breeze | | 3 to 4 knots | 8 |
| 4 | Moderate breeze | | 5 to 6 knots | 16 |
| 5 | Fresh breeze | in which the same ship could just carry closehauled | Royals, etc. | 24 |
| 6 | Strong breeze | | Single reefs and top-gallant sails | 32 |
| 7 | Moderate gale | | Double reefs, jib, etc. | 40 |
| 8 | Fresh gale | | Triple reefs, courses, etc. | 50 |
| 9 | Strong gale | | Close reefs and courses | 62 |
| 10 | Whole gale, with which she could only bear close-reefed main-topsail and reefed foresail | | | 78 |
| 11 | Storm, with which she would be reduced to storm stay-sails | | | 96 |
| 12 | Hurricane, to which she could show no canvas | | | 120 |

The estimate of the velocity here given is to be understood as only a rough approximation. That given by Sir Henry James,* according to which the velocity of the wind in miles per hour is found by multiplying the number of the Beaufort Scale by 7, is certainly one that cannot be accepted by any person to whom the Beaufort Scale is a practical reality of every-day life. And, besides, we all know that the opposition of the air, as a little boy trots away at a rate of not more than 4 miles an hour, is sufficient to raise a kite; and that if we put our heads out of the window of a railway carriage when the train is going 20 miles an hour, we find a fresh breeze very unlike the number 3 of the Beaufort Scale. But whether, with Sir Henry James, we take 1 as denoting a velocity of 7 miles or, as I have given it above, as showing only a velocity of 2, there may evidently be a good deal of motion in the air without its being sufficient to merit the name of wind.

An opinion very generally held by the inhabitants of temperate countries is, that the direction of the wind is fickle, uncertain, and subject to no fixed law; it requires, however, a very slight degree of attention to convince even the most casual observer that this is not the case, but that in every country winds from some one quarter predominate, whether throughout the whole year or through special months. The exact point of the compass from which the prevailing wind blows is commonly enough different in different localities, even when the distance between them is not great: at Greenwich it is about W.S.W., at Liverpool nearly W.N.W.; but in both places the excess of westerly winds is very great, whilst the regularity with which each spring these are interrupted by easterly ones, affords a familiar example of the change which is found so frequently to accompany the change of season.

To a description of the various parts of the world, from

* Instructions for taking Meteorological Observations, 1860, pp. 31, 32.

an anemological point of view, this chapter is devoted. It professes to be simply an exposition of geographical fact, and is based entirely on the testimony of very many competent and trustworthy observers, whether navigators, travellers, or residents. The one assumption which I have made—and that, indeed, rather as affording an easily understood system of arrangement than as embodying any theoretical assertion—is, that a range of mountains does produce some very decided alteration in the currents of air in its neighbourhood. Without examining now into what the alterations may be, it is a fact too familiar to require proof that every obstacle in the way of a current of air does affect it; that it breaks the force of the wind; that every house or tree has a weather and lee side; and that whilst on the one it may be almost impossible to stand against the violence of the blast, on the other there may be quiet, calm, and comfort. Even sheep on the bleak downs or open moorlands know this, and huddle under the lee of the low walls or of the occasional boulders, finding there shelter from the driving fury of the winter storm.

The difference is a very evident matter of fact; the cause of it is as evident; and I have, therefore, in describing various countries and the winds which prevail in them, assumed that a mountain chain forms a recognised line of separation between them, and renders it imperative to treat of them, in the first instance, as distinct. Further consideration may show that the separation is not always complete, and that winds cross geographical barriers either through imperfections in their line, or by passing over them, far in the upper regions of the atmosphere; but for purposes of description, the surface of the earth may be said to be divided by the principal mountain chains into a series of basins, a term which, applied to the oceans, I use in nearly the same sense as it is commonly used in as applied to rivers, that is to say, as denoting, in a general manner,

not only each particular ocean, but also all the country which drains into it. The principal of these, in which I will include all minor subdivisions, are:—

1. The Basin of the North Atlantic.
2. The Basin of the South Atlantic.
3. The Great Southern Ocean.
4. The Basin of the North Pacific.
5. The Basin of the South Pacific.
6. The Basin of the North Indian Ocean.
7. The Basin of the South Indian Ocean.

On a description of the physical nature of these, and, in greater detail, of the winds which, throughout the year or in different seasons prevail in the different parts of each, I now enter.

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## SECTION II.

### The Basin of the North Atlantic.

By the term Basin of the North Atlantic, I mean that part of the northern hemisphere which is bounded on the west by the Rocky Mountains and the high land of Mexico and Central America; on the east, by the Ural Mountains, the Caucasus, and the mountains of Asia Minor, Syria, Upper Egypt, and Abyssinia. It thus includes, in addition to the North Atlantic Ocean, the whole of Europe and of North Africa, and by far the largest part of North America.

The western boundary which I have assigned to this basin is unmistakeable. The Rocky Mountains, always of a great height, and occasionally towering beyond the line of perpetual snow, stretch from the extreme north, without any break, though under different names, to the Isthmus of Panama; and form, geographically speaking, part of the mountain chain which extends to the southern extremity of South America.

These mountains are—as the name given to such a large portion of the range points out—of an extremely rocky and rugged character. The mountain district, which is, on the average, nearly 500 miles broad, consists of several distinct parallel ranges, rising from a very elevated table-land, and laced, as it were, together by transverse or cross ranges, of a height not inferior to the others. The country is thus divided into several inland basins; the principal of which has attained a certain political importance, from its having been selected, on account of its separation from the outer world, as the home of the Mormons. The scenery throughout is of the wildest character. Precipices and gorges of the most stupendous depth are common, and tend to render the passage of the mountains not only difficult, but, in most places, absolutely impossible.

This long, broad, high, rugged mountain chain, running nearly parallel to the West Coast of North America, that is to say, in a mean direction of from N.N.W. to S.S.E., thus stands as a barrier in the course of all winds that blow near the surface of the earth in a westerly or easterly direction; and as such must be considered as a well-marked line of separation between the winds on their eastern and western sides.

East of the Rocky Mountains, the territory of the United States is mapped out into divisions which differ from each other, in respect to climate, in a very decided manner. There are regions where it rains almost constantly; regions of extreme fertility, where Nature seems to run riot in the exuberance of vegetation, where the care of the settler has been to repress, rather than to encourage, and where a few years of neglect throws back the country to its former condition of almost impassable jungle. There are, on the other hand, wide districts where it scarcely ever rains at all, where the soil is sand or salt, and where there is but

a more or less scanty growth of sapless and bitter herbs; and between these extremes there are districts of every degree of fertility or barrenness. The thermometric range is similarly very great. During summer the temperature is uniformly high, from the coasts of the Gulf of Mexico to the extreme north; but in winter the difference is excessive; and whilst in the lower part of the Mississippi Valley the mean temperature of 55° speaks of a very much higher ordinary temperature, the severity of the season in New York or Quebec is well known, and in the more remote parts of the Hudson's Bay territory an almost fabulous cold prevails, —70° Fahr. having been actually registered by our exploring parties at stations on the shores of Great Slave Lake or of Great Bear Lake.*

But over this enormous area of country, and notwithstanding these very striking differences of climate, there is no obstacle which can break the continuity of the movements of the atmosphere. From the eastern foot of the Rocky Mountains to the western base of the range of the Alleghânies, the country is an almost uninterrupted plain; not, indeed, a dead level, but rising, on each side of the Mississippi, in a gentle, uniform slope.

Standing out of this plain, the Alleghanies might appear to present an obstacle to the passage of atmospheric currents; the range runs from N.E. to S.W., and though the height it attains is small, as compared with that of the Rocky Mountains, it is still very considerable. For nearly 1,000 miles, from Alabama to Vermont, it has an average height of nearly 3,000 feet above the sea, and isolated peaks rise a good deal higher. The slope, however, is extremely gentle: the character of the Alleghany scenery, in marked contrast to that of the Rocky Mountains, is peaceful and rich; the sides are clothed with thick vegetation, which passes over the top without any check, so

* Lieut. W. H. Hooper: Tents of the Tuski, p. 383.

that from an agricultural point of view, the three, four, or five distinct and parallel ridges, which form the mountain district, are merely undulations of a size somewhat larger than usual. These ridges, covering a breadth of about 150 miles, are separated from each other by long parallel valleys; and far from being interlaced one into the other, like the component parts of the great western chain, the ridges themselves are constantly cut by large rivers, which break through, whether on the west or the east, as tributaries to the Mississippi or the ocean. And although such an elevated mass of land must prevent the free passage of easterly or westerly winds, it is clearly established, by American researches, that the influence which these mountains exercise on the climate of the United States is extremely slight, and that we find "vegetable and forest growths, and forms of cultivation, at two to three thousand feet elevation in Virginia, which differ very little indeed from those of the plains at or near sea level on each side; and no difference whatever of a climatological origin between the opposite bases." *

On the east, the boundary of this great basin is much less clearly marked: there are no impenetrable ranges of high mountains, or elevated table lands forming a distinct line from north to south. The mountains of Norway do, indeed, run in that direction for nearly a thousand miles; and though the range ends abruptly, its line is, at some distance to the south, resumed by the Alps and Appenines, backed up by the lofty mountains of Tyrol, Carinthia, Turkey, and Greece. The Pyrenees, too, the high land of Spain, and the mountains of Portugal, carry the barrier to the south on the west. All these must necessarily exercise a very decided influence on the circulation of the lower atmosphere; and the coast of Europe may be considered as forming, to a certain extent, the eastern boundary of

* LORIN BLODGET: Climatology of the United States, p. 133.

the basin. Still, there is in this line the very large interval between the southern extremity of the Scandinavian mountains and the northern part of the Alps, a breach which is very imperfectly guarded by the comparatively low and disconnected mountains of Ireland and Scotland. Considered as a boundary, it is far from presenting such an impassable barrier as the Rocky Mountains; and the atmospheric system of Central and Eastern Europe seems to be so closely connected with that of the western part of the continent, that I feel obliged to fix the boundary further east, so as to embrace the plains of Russia; but I do so with some hesitation, considering the Ural mountains in the background merely as a secondary barrier, which closes the gap left in the first more decided one; and at the same time doubting whether they really act as such, or whether the true line of separation is not still further to the east in numerous mountain ranges which, under various names, and in apparently entangled directions, stretch away towards the north-east from the highlands of Central Asia.

In the North Atlantic Ocean, between the parallels of 25° and 10°, there blows with almost uniform steadiness a wind, whose direction varies between north and east. The northern and southern limits of this wind—which at a very early period received the name of the NORTH-EAST TRADE WIND — move backwards and forwards as the seasons change. In the summer they recede from the equator, attaining their greatest distance in July, when the trade wind is frequently met with as far north as 30°, and rarely extends to the southward of 10° N., sometimes even not reaching so far. In winter its limits move south, and in January THE TRADE seldom blows to the north of 25°, whilst it reaches at this season as far south as 2° or 3° N.; but, at all times of the year, it blows regularly between

the parallels of 25° and 10° N., and in mid-ocean, between the parallels of 20° and 15°, has a pleasant steady force, which has rendered THE HEART OF THE TRADE almost a synonym for fair-weather sailing. Here its direction is N.E., and from that varies scarcely a point either way; but, to the north-east of this position, its mean direction is much more northerly, and, to the west, is much more easterly.*

Down the coast of Africa, past the Canary Islands, and towards the Cape de Verdes, it blows steadily from about N.N.E., gradually becoming more easterly as it decreases its latitude. On the other hand, it blows past the West India Islands, and into the Caribbean Sea, or Gulf of Mexico, as a wind often east, and at times even from the south of east. In this western part of the sea, it is by no means unusual for it to blow from E.S.E.; and, though it very commonly blows from some point to the north of east, its mean direction is not very far from due east.†

On the eastern side of the ocean, after passing Cape de Verde and the Cape de Verde Islands, where the largest part of this atmospheric current turns to the west, a very considerable branch is thrown off to the southward: this seems to spread out in a fan-like manner, and blows in part as a northerly wind, in part as a wind from some point to the west of north, and occasionally blows to the African coast from the W.N.W., or even west. This

* I have, throughout this chapter and the whole work, used the technical notation of the points of the compass whenever I have meant the bearing to be understood as accurate. Speaking of a bearing in loose terms, I have written it in full—thus, by N.E., I mean that point strictly, or very nearly so; by north-east I mean, in general terms, some point in the north-east quadrant.

† HUMBOLDT: Personal Narrative, trans. by Williams, vol. ii. p. 3. —MAURY: Pilot Charts of the North Atlantic; Series C.—Wind Charts of the Board of Trade.—ADMIRALTY: Wind and Current Charts of the Atlantic. 1868.

branch has, however, neither the strength nor the steadiness of the main current which turns to the west: it is very fitful, more particularly in summer and autumn, when it often dies away altogether, and is succeeded by calms, squalls, and heavy rain. In the winter it blows more steadily, often reaching nearly to the line, and turning as a north-westerly wind into the Gulf of Guinea.

The accounts and observations which we have from the interior of North Africa are few in comparison to those from the ocean; but they are sufficient to show that the north-easterly and easterly wind which blows over the sea, blows also over the land, though not, indeed, with quite the same regularity and steadiness. The notices of it are frequent in the narratives of those who have travelled in the Great Desert. The register kept by Captain Lyon, or his unfortunate companion, Mr. Ritchie, during a stay of six months, from May to October, at Murzuk, shows an almost undeviating persistence of easterly winds, commonly between N.E. and E., but varying not unfrequently to S.E.* These often blew strongly, filling the air with clouds of fine sand to such an extent, that it was impossible to see more than a few yards. According to Caillié, who perhaps saw more of the Desert in its worst form than any European before or since, a wind varying from N.E. to N. prevails at Tinné in the months of December and January.† During a boat journey on the Niger, or Dhioliba, from Jenné to Timbuctoo, in March and April, he experienced almost constant winds from the north-east, more or less strong.‡ During a fortnight that he stayed at Timbuctoo, in April, the wind never ceased to blow from

* Captain G. F. LYON, R.N.: Travels in North Africa, 1821, p. 355, *et seq.*

† RÉNÉ CAILLIÉ: Travels through Central Africa to Timbuctoo, and across the Great Desert to Morocco, vol. i. pp. 337, 345.

‡ *Ibid.* ii. 28.

the east,* and during his journey due north across the Desert, in May, the east winds, which alternated with stifling calms, were the cause of his most acute suffering.† These easterly winds were in all cases extremely hot and parching, and frequently carried dense clouds of sand along with them. His description of one of these sand storms is remarkable. It was on the 23rd of May. He says:—"What distressed us most during the horrible day was the pillars of sand, which threatened every moment to bury us in their course. One of the largest of these pillars crossed our camp, overset all the tents, and, whirling us about like straws, threw us one upon another in the utmost confusion. We knew not where we were, and could distinguish nothing at the distance of a foot. The sand wrapped us in darkness like a thick fog, and heaven and earth seemed confounded and blended into one. Whilst this frightful tempest lasted, we remained stretched on the ground motionless, dying of thirst, burned by the heat of the sand, and buffeted by the wind. We suffered nothing, however, from the sun, whose disk, almost concealed by the cloud of sand, appeared dim and shorn of its beams."‡

The sand which easterly winds thus raise in the Desert is carried by them far out to sea. During the summer it fills the air as far as the Canaries, and to the height of the Peak of Teneriffe with an impalpable dust, which has the effect of a thick haze;§ and at all seasons of the year ships, even at a considerable distance from the shore, find it covering their sails and decks. In the winter, and more especially in the months of January and February, this north-easterly wind often blows over the land considerably

* RENÉ CAILLIÉ: Travels through Central Africa to Timbuctoo, and across the Great Desert to Morocco, vol. ii. 88.

† *Ibid*, ii. 112. ‡ *Ibid*, ii. 114.

§ C. PIAZZI SMYTH: Teneriffe, an Astronomer's Experiment, *passim*.

to the southward of the Great Desert, and off the coast between Cape de Verde and Cape Palmas, some distance to seaward. It here has the local name of THE HARMATTAN, but its characteristics are in no respect different from those which mark the same wind further to the north throughout the year. It is described as, at Sierra Leone, "sometimes blowing strongly from the eastward, at others nearly sinking to a calm, but always attended with a peculiar drying effect, and wafting through the atmosphere a prodigious quantity of red sand or earth reduced to an impalpable powder."*

On the eastern side of the Atlantic Ocean, through several degrees to the North of the region of the trade wind, there prevails during the greater part of the year a wind, the direction of which varies between N.W. and N.E. South of the parallel of 35° N., it is found at all times of the year, blowing into the trade, a fresh, steady breeze, stronger than the trade, strictly so called, but, in other respects, scarcely to be distinguished from it. It does not, however, blow with the same perfect regularity, and a westerly or south-westerly wind occasionally, more particularly in winter, sweeps home to the African coast. Further north, the interruptions to it are more frequent. During the winter months, light winds and gales from the southward and westward are not uncommon on the coast of Portugal, where they are accompanied by heavy rain, which converts the trickling mountain streams, nearly dry throughout the summer, into foaming torrents. These, however, are exceptional. The south-westerly wind seldom blows for more than a few days at a time, and veering through west, becomes fixed again at nearly due north. Through the rest of the year the northerly wind has a very marked predominance, and reaches into the trade, blowing

* Parliamentary Blue Book, Feb. 17, 1830, p. 64.

freshly the whole way. Outward-bound ships fairly count on falling in with it when they are abreast of Cape Finisterre, and ships coming home from Lisbon or Gibraltar have, as a rule, to stretch out to the westward as far as the meridian of 15° or even 20° W., in doing which, since the wind is, for the most part, from the west of north, they are not unfrequently driven a long way to the southward, and have been known to touch at Madeira on their way to England.

Over the Mediterranean, also, northerly winds very decidedly prevail. Admiral Smyth says that, from west round northwards to N.E., they "occur with little intermission for nearly two-thirds of the year, and pretty constantly so in summer."*

In the Archipelago, and the Levant generally, winds from the north-east blow all through the summer with great constancy: they are ushered in by north-westerly winds, which prevail through March and April; but about the end of April they become settled, and continue with little change till towards the end of September. Through the winter northerly winds, frequently very heavy gales of some days' duration, are still common; but the weather is unsettled and sharp, dangerous squalls from various quarters often intervene. The northerly winds of winter are especially dreaded, "since they are often accompanied with storms of hail, sleet, and snow, insomuch that the navigation amongst so many islands becomes extremely dangerous to a stranger. During one of these, in the year 1771, a Russian three-decker was driven from her anchorage at 'Psara, and thrown upon the Kalogero rocks, where every man perished; a Turkish 64-gun ship shared a similar fate a few years afterwards, and the disasters to

* Admiral W. H. Smyth: The Mediterranean; a Memoir, Physical, Historical, and Nautical, p. 233.

smaller vessels in the north wind are both numerous and distressing." *

In December, 1833, the French line-of-battle ship, "Superbe," driven by another of these northerly gales from the neighbourhood of Smyrna, traversed nearly the whole length of the Archipelago by day only to be utterly lost on the coast of Paros by night; and Admiral Jurien de la Gravière, in narrating the circumstances, concludes:— "The loss of the 'Superbe' created a great sensation. It was forgotten that Admiral Collingwood, a man who had grown old amid the severe trials of a sailor's life, had declared that it was impossible for ships of the line to keep the sea, in the Greek Archipelago, in winter. People were astonished that a line-of-battle ship should be lost. They ought rather to have been grateful to Providence that, in such a terrible disaster, happening under such circumstances, a crew of eight hundred men had been saved." †

In the west part of the Mediterranean there is the same prevalence of northerly winds throughout the year, and more particularly in the summer. The preponderance is so great that the passage from Algiers to Toulon is, on the average, one-fourth longer for a sailing ship, and one-tenth longer for a steamer, than is the passage from Toulon to Algiers. In winter the weather is broken; and extremely heavy gales, almost always from the north or N.W., are frequent. These were the gales which, in the old French war, told so severely on both men and ships off the coasts of France and Corsica: in one, in December, 1808, the "Ocean," a three-decker, Lord Collingwood's flag-ship, very nearly foundered; and in another, unusually late in the season, May 20th, 1798, the "Vanguard," Lord Nelson's flag-ship, was dismasted; whilst, further to the

* Admiral W. H. SMYTH: The Mediterranean; A Memoir, Physical, Historical, and Nautical, p. 273.

† La Marine d'Autrefois, p. 71.

eastward, the same gale, blowing with less force, swelled the sails of the ships which were carrying Bonaparte and his army to Malta and Egypt.

On the 21st of January, 1841, a squadron of five ships of the line left Toulon to go to the roadstead of Hyères. The wind from N.W. gradually got up, till, during the night, it blew with great violence: the ships separated in the darkness, and only one made the appointed anchorage. The storm continued for four days, increasing in fury; it veered to the north, and swept the Mediterranean from one end to the other. Of the rest of the French squadron, the "Océan," the flag-ship, a large three-decker, was for a time in very great danger. Her sails were all blown away, and she rolled so heavily as to dip her mainyard, and to burst in three of her ports: she finally made the Bay of Palmas in Sardinia. The three others, having all sustained much damage—one with her bowsprit sprung—got into Cagliari. The same gale swept down the coast of Spain, and blew in its full strength in the channel between Spain and the Balearic Islands, where Admiral Jurien, then the commander of the "Comète" brig, very nearly ended his career prematurely. "The English," he says, "rallied us when they learnt the fate of this squadron, saying that we were nothing but fair-weather sailors. And yet the ships of Nelson were not more fortunate in May, 1798, than ours were in January, 1841; the damage they sustained was even more severe. But the fact is, that in certain exceptional gales, the only knowledge that is of much use is a knowledge of the way to avoid them."*

In the Adriatic, also, very violent gales from the north are common during the winter; and at Malta, further to the south, few seasons pass without a north-easterly storm. This, when it comes, blows straight into the Grand Harbour, and causes great damage, especially to the small

* La Marine d'Autrefois, p. 174.

craft which line the wharves all along the Marina. The lower battery of Fort Sant' Angelo has been repeatedly destroyed by the force of the sea, the guns dismounted and hurled far to the rear of their embrasures, and the breaking water carried in sheets rather than spray over the fort, and over the neck of land on which stands the old town of Il Borgo, on to the decks of the ships lying in Dockyard Creek.

These northerly winds of the Mediterranean have had, from the earliest times, individual names, peculiar to the different localities, assigned to them; and it is by these names that they are almost always spoken of, not only by natives of the various countries, but by travellers generally. Thus the north-west wind of the Gulf of Lyons, and on the west coast of Italy, is the MISTRAL, a name which, derived from the Italian word "maestro," a master, would seem to refer both to its prevalence and its occasional strength. A northerly storm in the Adriatic is a BORA—a name handed down from classical times.* A north-easter, at Malta, is a GREGALE, a Greek wind; and, in the Archipelago, the summer winds are THE ETESIAN, also a classical name;† whilst a winter gale is a TRAMONTANA, or a TRAMONTANA NEGRA, a black norther.

In the eastern part of the Mediterranean, the northerly winds reach to the African coast, continue over Egypt and the Nubian Desert, and have even been felt on the Nile as far south as 8° or 9° N.‡ In the west, on the other hand, easterly winds, which are called LEVANTERS, blow frequently: these, during the summer, prevail in a very marked manner along the coast of Africa, between Cape Bon and the Straits; but, during the winter, a westerly or south-

* Boreas, the north wind. † ἐτήσιος, annual.

‡ Capt. J. H. SPEKE: Discovery of the Source of the Nile, p. 603—Sir SAMUEL W. BAKER: The Albert Nyanza, Great Basin of the Nile, 51.

westerly wind often blows continuously for several weeks.

The very general prevalence of northerly winds throughout the Mediterranean is, however, interrupted at times by winds from the opposite direction. In the winter, strong southerly and south-westerly gales are sometimes experienced on the coast of Sardinia, in the Ionian Sea, and in the Archipelago: in the summer, a scorching south-westerly breeze occasionally passes over Malta; but the best known of all these exceptional winds is the south-easter, or SCIROCCO. This wind, hot, damp, and often loaded with red sand, blows not unfrequently during the spring or autumn; and is peculiarly disagreeable in the southern parts of the sea, and in Malta or Sicily, where it induces a feeling of lassitude which makes life itself seem a burden. Admiral Smyth says: "The thermometer does not at first experience any very sensible change, though it slowly rises with the continuance of the scirocco to 90° and 95°, which last is the highest I have observed, though the feelings—which are certainly a very inaccurate measure of actual heat—seem to indicate a much higher temperature; but the hygrometer shows increased atmospheric humidity, and the barometer gradually sinks to about 29·60 inches. This wind generally continues three or four days, during which period, such is its influence, that wine cannot be well fined, or meat effectually salted: oil-paint laid on while it continues will seldom take or harden; and while, from seeming dryness, it rives unseasoned wood, and snaps harp-strings, it makes metals oxydize more readily, mildews clothes, and renders everything clammy."* "It is more frequent in the spring and autumn than in the summer, and in winter possesses no disagreeable qualities."† Even in the other seasons, these are considerably modified

* *Op. cit.*, p. 252. † *Ibid*, 253.

during its passage north over the sea, and as a soft warm southerly wind it reaches the coast of Provence, where, in the form of "blood-rain," or in Switzerland, as "red-snow," its moisture and sand fall together.*

In the Atlantic Ocean, to the north of the parallel of 35°, there is a very decided prevalence of winds from the westward. These westerly winds extend far to the north—as far, perhaps, as we are able to give any accurate account of the winds at all. Their directions vary slightly in different localities, and at different seasons of the year: in the southern and south-western part of this broad region they blow almost continuously from S.W., or veering from that to west; and are often found much further south, near the American coast, during the summer months, when southerly and south-westerly winds are common on the coasts of Florida and Georgia. In the south-eastern part, on the other hand, they come round to the north of west, and as they approach the shore often veer through north towards north-east. Further to the north, across the whole breadth of the ocean to the northward of the parallel of 45°, they range between N.W. and S.W., blowing more from the northward of west during the summer months, and from the southward during the winter; but, as westerly winds, they have a marked preponderance throughout the year. During March, April, and May, indeed, winds from between north and east are frequent; and an easterly wind, lasting even for weeks, is not uncommon; but at any other season such a thing is extremely rare. On the east coast of Greenland, however, the prevailing wind is from the north-east; and throughout the whole of the Arctic regions the direction of

* This origin of the hot wind of Switzerland, and of the "blood-rain" which sometimes accompanies it, has been doubted. The question is discussed in a subsequent chapter.

the violent winter storms has been found to be, for the most part, between N.W. and N.E.*

These westerly winds, prevailing over such a large area of the North Atlantic, are well known to the homeward-bound ships coming from long voyages, from India, China, the Pacific, or Australia. Such ships, having been obliged by the north-east trade to keep well to the westward, when they get to the northward of 35°, count on finding, and generally do find, strong fair winds, which our sailors have named, from the latitudes where they blow with the greatest steadiness, THE ROARING FORTIES. In winter, especially, they blow with great and often with dangerous force, reaching home to the narrow seas with destructive violence. Almost without exception, the gales which, winter after winter, make such terrible havoc amongst the shipping on our coast are from the west. It would be easy to give a long list of winter storms which, by their deadly fury, have earned a distinct reputation. The gale of January 6th, 1839; that of October 25th, 1859, when the "Royal Charter" was dashed to pieces on the Welsh rocks; and the succession of furious storms in January, 1866, in one of which the "London" foundered in the Bay of Biscay—storms of our own time, the fatal effects of which will long live in the minds of our seafaring population—were all instances of the terrific force with which these westerly winds, at times, hold on their way. Further back was, to mention one more instance, the celebrated storm of November 27th, 1703. This, which has for many ages been known emphatically as the Great Storm, has perhaps a more distinct historical reputation from its use to Addison in the celebrated lines, the corner-stone of his literary

* Sir LEOPOLD MCCLINTOCK: Meteorological Observations in the Arctic Seas; in Smithsonian Contributions to Knowledge, vol. xiii. pp. 69, 70.

fame, in which he compares the Duke of Marlborough to the destroying angel, who—

"Rides in the whirlwind and directs the storm." *

Contemporary writers have left us very detailed accounts of this storm, and of the damage it did; and they agree in this, that it began from the south-west, and veered towards north-west; "and still the more northward it shifted, the harder it blew."†

During the summer, our westerly winds have seldom such a destructive force; they prevail then from west, or from the northward of west; are for the most part mild and genial in their nature; and when they come from the southward are warm, moist, and commonly accompanied either by rain, or by that close, damp weather, which is colloquially known as "muggy."

Over the whole of the northern part of the continent of Europe there is the same prevalence of westerly winds which is observed over the ocean. From a mean direction of nearly due west they blow during at least three-fourths of the year over the plains of Germany and Russia, extending quite to the Ural Mountains, and even beyond them into Northern Asia; for these mountains are by no means so lofty or so unbroken as to present an absolute barrier to the passage of atmospheric currents: and to the southward of Russia they blow very commonly over the Black Sea, more especially in the autumn and winter, when they have a strength that has made that sea proverbial, from the earliest ages, for its dangerous navigation. As over the greater part of the Mediterranean, northerly winds prevail during the summer, but at other seasons westerly

* The Campaign.

† PAUL CHAMBERLEN: History of the Life and Reign of Queen Anne, p. 127—LUKE HOWARD: Climate of London, vol. i. p. 255. See also a quaint Letter from Mr. William Derham, in the Philosophical Transactions for 1704.

winds are the rule, and violent westerly storms frequent. "At Kalla and Poli, on the east coast of the Black Sea, the hardest gales are almost invariably from the west, throwing up a rise of four feet in the waters along the shores of Mingrelia, and at the same time causing the rivers to overflow their banks on the low grounds of that neighbourhood."*

Between these westerly winds and the north-east trade there is a part of the ocean where the winds are of the most changeable character; this district is bounded on the south by the trade, and on the north by the westerly winds, so that its latitude varies with that of the northern limit of the trade, increasing in summer and diminishing in winter; in longitude it lies for the most part between the meridians of 30° and 55° W., though it often stretches out to the west nearly as far as the American coast. In this region, wherever it may be, at any particular season variable winds are found, or, very frequently, no wind at all. Winds from all quarters, N.E., S.E., S.W., or N.W., and dead calms occur in very nearly equal proportions; severe gales are common, and the same uncertainty exists with regard to them that exists with regard to the general direction of the wind; they blow from all quarters, but, perhaps, most frequently from the S.W. Speaking roughly, this part of the ocean lies between the Azores and Bermuda, and at a very early period in Atlantic navigation received from the Spaniards the name of *el golfo de las yeguas*, the mares' sea, in allusion to its boisterous nature and in contradistinction to *el golfo de las damas*, the ladies' sea, as the trade wind region was called, from its being so smooth and pleasant to sail over. It is this name, *el golfo de las yeguas*, which our sailors translated into THE HORSE LATITUDES;† and the story of ships

* SMYTH: Mediterranean, p. 281.

† There are, however, many instances in English in which the word

laden with horses being becalmed so long that they had to throw their cargo overboard was probably invented at a comparatively recent date, to account for the name which the region has so long borne.

To the east of this, the trade is well marked considerably to the north of its average latitude across the Atlantic, and though between the parallels of 28° and 40° the winds are still variable, they are so in a different manner from what they are in the part of the ocean we have just been considering, as they prevail very decidedly from N.W., North, or N.E.; a south-easterly wind is uncommon, and a calm almost unknown. To the west, on the other hand, the south-westerly wind becomes prevalent at a comparatively low latitude, and most markedly so in the summer—a fact in noteworthy opposition to what takes place on the other, or east side of the ocean, where the westerly wind comes nearest to the equator in the winter.

The westerly winds, which so largely predominate over the ocean to the northward of 35°, are experienced also on the American continent. To the northward, as far as observation enables us to speak with any certainty, they are found with a direction that is often very nearly due north; and over almost the whole of the northern part of the continent their direction is from the north of west; but it gradually becomes more westerly, and then south-westerly as the latitude diminishes; and, although the northing is found further to the south in winter than in summer, still, to the south of the parallel of 40°, the mean direction is very decidedly from the south-west. West of the meridian of 90°, however, winds from the south or south-east are very frequent, particularly in summer; and, south of the parallel of 35°, such winds are general. In the Southern States of the Union—in Mississippi, Louisiana,

*horse* is used as a prefix denoting boisterous; as, for instance, a *horse-laugh, horse-play.*

and more especially in Texas—they blow during the summer months almost without intermission; but, in the winter, winds from between N.W. and N.E. are common. The northerly winds have often great strength, and bring a biting cold otherwise unknown in such low latitudes. The thermometer has been known to fall from 70° or 80° to freezing point in less than ten minutes, the northerly wind coming on suddenly and with great violence. Storms of such a nature seldom last more than three days; but during the months of winter northerly winds of greater or less force may be considered as prevailing.*

These northerly winds of winter blow also with great frequency in the Gulf of Mexico, as well as in the Caribbean Sea, reaching all along the coast of Central America. Eastward, they are often found as far as the east end of Cuba, and in the Florida Channel they blow with great violence. These are the winds that have from the earliest times been known distinctively as NORTHERS, and they are, for the most part, strong, steady gales, lasting for three or four days, rendering the anchorages exposed to the north very insecure, and dangerous enough for ships caught on a lee shore. "Nevertheless," says Dampier, writing two hundred years ago, "when our Jamaica logwood ships are coming loaden out of the Bay of Campeachy, in the north season, they are glad to have a north. For a good north will bring them almost to Jamaica; neither have any of our vessels miscarried in one of these storms that I did ever hear of, though sometimes much shattered; but the Spaniards do commonly suffer by them, and there is seldom a year but one or more of them are cast away in the Bay of Campeachy in this season."† Notwithstanding

* JULIUS FRŒBEL: Seven Years' Travel in Central America, Northern Mexico, and the Far West of the United States, p. 448.

† Captain WILLIAM DAMPIER: Voyages and Descriptions, 1699, vol. ii. part iii. p. 62.

their name, they are, in reality, north-westerly winds. In the Gulf of Mexico they blow strongest at N.N.W., and outside the Gulf, amongst the islands, they are still more westerly.* They are thus quite distinct in direction as well as in character from the trade wind, which—as has been already said—blows past the islands and into the Gulf of Mexico as a wind almost due east. This easterly wind is the prevailing wind of the Gulf; and in the northern part it most commonly veers to the southward, so that it blows on to the coast as a south-easterly or southerly wind. During the summer, and, indeed, through the greater part of the year, it has this direction almost continuously on the coasts of Louisiana and Texas; but, towards the middle of winter, the northerly winds, of which we have just spoken, are somewhat more numerous, as well as more noticeable from their frequent violence.

Further south, a branch of the trade wind blows home to the coast of South America as a wind from about E.N.E., bringing with it fine, clear weather. From May to November, however, this is interrupted: winds from the south-east prevail along the coast, and winds from west and south-west, which are called VENDABALES, frequently intervene. These westerly winds are accompanied by damp, unpleasant weather, or by deluging rains. In Carthagena, for example, during their continuance "there is almost a continual succession of thunder, rain, and tempests; the clouds precipitating the rain with such impetuosity that the streets have the appearance of rivers, and the country of an ocean."†

But even at that season these winds are not experienced far from the coast; and when well clear of the land, the

* Captain WILLIAM DAMPIER: Voyages and Descriptions, 1699, vol. ii. part iii. p. 60.

† ULLOA: Voyage to South America; in Pinkerton's Collection, xiv. 338.

wind prevails from the eastward throughout the year, blowing through the winter from about E.N.E., and through the summer more commonly from the southward of east. These south-easterly winds are undoubtedly winds from the South Atlantic, which at that season stretch to the north of the line; and we shall have occasion to refer to them again in the next section.

The West India Islands and their neighbourhood are subject to very violent storms, known distinctively as HURRICANES, which occur indeed at all times of the year, but most frequently during the autumn. The number of those which have been recorded in other months is scanty in proportion to those in August, September, and October. According to observations, which extend now over nearly four centuries, they occur in the several months of the year in the following ratio—the numbers being proportional parts of 100:—*

| January. | February. | March. | April. | May. | June. |
|---|---|---|---|---|---|
| 1·5 | 2 | 3 | 2 | 1·5 | 3 |
| **July.** | **August.** | **September.** | **October.** | **November.** | **December.** |
| 7 | 28·5 | 24 | 20·5 | 5 | 2 |

These storms are distinguished from all others of the Atlantic by their excessive and destructive violence; by the uncertainty of the direction of the wind; by the rapidity with which that direction changes, the wind flying round almost suddenly to a different, sometimes even to the exactly opposite, quarter; by their being commonly accompanied by a rising of the sea, known as THE STORM WAVE, which, as it breaks on the shore, inundates the land to a great depth, and with terrific force; by deluging rains, and frequently by extraordinary manifestations of electric disturbance, either as thunder and

* BLODGET: Clim. of the U.S., p. 402.

lightning, or in the form of meteoric fires of remarkable size and brilliancy.

Another and very noticeable peculiarity of these storms is the almost uniform manner in which they pursue a given track. For the most part, they commence somewhere to the east of Barbadoes between the parallels of 10° and 15° N., and travel from there in a direction very nearly W.N.W., till they reach the neighbourhood of Florida, when they generally alter their course to the northward, and follow the line of the coast to about the parallel of 40°; there they turn to the eastward, and are lost in the ocean. They do not, however, retain their extreme violence so far to the northward: they blow, indeed, as tremendous gales, in which the direction of the wind shifts in the most sudden and dangerous manner; but the intensity which distinguishes them in and near the tropics is seldom experienced beyond the coast of Georgia.

Frequently, however, they do not turn to the north, on the coast of Florida. If their W.N.Westerly course carries them to the southward of that peninsula, they pass into the Gulf of Mexico, where they curve to the north; and the storm wave often breaks with most destructive effect on the low lands in the neighbourhood of New Orleans. Those that follow this track do not seem to go far inland; and there are no recorded instances of their being experienced to the west of the Alleghany Mountains.*

The fearful disasters both on sea and land, the loss of life and property which are so frequently caused by hurricanes, have invested them with a sensational interest, in addition to that interest which a scientific inquirer would necessarily feel in a class of storms which differ so markedly from all other storms, and which are so frequently accompanied by phenomena so peculiar. But these very pecu-

* BLODGET: Clim. of the U.S., p. 400.

liarities appear so irresistibly to connect them with other storms, which, at fixed times of the year, spread ruin and destruction in certain other localities, that I am induced to defer the more particular consideration of them until, after having given a general account of these others, I am enabled to discuss, in greater detail, the points of resemblance and the points of difference, as well as the agencies which have been supposed to produce them.

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## SECTION III.

THE BASIN OF THE SOUTH ATLANTIC—THE GREAT SOUTHERN OCEAN.

UNDER the name Basin of the South Atlantic, I include, in addition to the South Atlantic Ocean, all the continent of South America to the east of the Andes, and the western part of South Africa.

Our very limited acquaintance with the interior of Africa prevents our assigning any exact boundary on the east; and renders it even impossible to say whether there is in South Africa any barrier at all to the comparatively free passage of atmospheric currents from east or west. There are, indeed, high lands and mountain districts of considerable extent; but they are neither rugged, lofty, continuous, nor in any way difficult of passage. Dr. Livingstone's general description of South Africa, north of the English settlements, may, perhaps, be considered as embodying all that is really known of this part of the continent. He supposes lines to be drawn dividing the country into three "zones," running north and south, and says:—

"The eastern zone is often furnished with mountains, well wooded with evergreen succulent trees; and its seaboard gorges are clad with gigantic timber. It is also comparatively well watered with streams and flowing rivers. The annual supply of rain is considerable.

"The next division, that which embraces the centre of the continent, can scarcely be called hilly, for what hills there are, are very low. It consists, for the most part, of extensive, slightly undulating plains. There are no lofty mountains, but few springs, and still fewer flowing streams. Rain is far from abundant, and droughts may be expected every few years.

"The western division is still more level than the middle one, being rugged only near the coast. It includes the great plain called the Kalahari Desert."*

We may thus consider the two western "zones" of these three to be included in the basin of the South Atlantic, and may place the boundary in the easternmost division of high land. From the description just given, it must, however, be little more than a geographical line of demarcation, and cannot be considered as effecting any complete separation between the winds on its eastern and western sides.

On the west, the Andes at once offer themselves as the boundary of the basin; such an enormous mass of high land, the lowest points of which have an elevation of not less than from ten to fifteen thousand feet above the sea, constitutes a barrier which no wind, near the surface of the earth, can pass. Compared with this, all the other mountain ranges of South America are dwarfed into insignificance, and yet some of them are by no means small, and the effect which they produce on the atmospheric currents must be considerable.

The mountains of Venezuela rise in many instances to a height of 7,000 feet, and form several distinct ranges, running in a general direction of from west to east on both sides of the Orinoco. The mountains of Brazil, again, in several ranges running nearly north and south, extend over a breadth of many degrees of longitude; but

* DAVID LIVINGSTONE: Missionary Travels and Researches in South Africa, p. 95.

they are not, as a rule, of any great elevation. Itambe, the loftiest peak of the principal range, the Sierra do Espinhaço, is not quite 6,000 feet above the sea, and many of the others would seem to be little more than hilly ridges, rarely attaining a height of two or three thousand feet.

And with the exception of these mountain districts, in which the mountain chains are short, as compared with the enormous extent of the continent, the whole of South America is a series of very flat, and, for the most part, low-lying plains. The *Llanos*, as the plains of the upper part of the Orinoco are called, are less than 300 feet above the sea, and are so uniformly level, that during a great part of every year they are covered with water, so as to form a large inland sea, whilst during the dry season, they become an arid desert. On the south they join on to the *Selvas*, or forest region of the Amazon, a plain of an extent nearly equal to that of European Russia, which is covered with impenetrable wood, so that, except on the rivers, it still remains almost entirely unknown. The rivers, however, are very numerous, and their streams, for the most part feeble, bear evidence to the level nature of the country. Far inland, up the tributaries of the Amazon in the second and third degree, the oceanic tide is, at times, distinctly perceptible, and through many degrees of latitude, as well as of longitude, the rise of the land is extremely slight.*

Still further south are the plains known as the *Pampas*, which extend from the sea to the Andes, and from the

* HENRY WALTER BATES: The Naturalist on the Amazons, vol. ii. p. 123. For this almost uniform level of the valleys of the Amazon and of the great Southern Tributaries, see also A. R. WALLACE: Travels on the Amazon and Rio Negro, pp. 418—420; W. CHANDLESS: Ascent of the River Purus, in Journal of the Royal Geographical Society, vol. xxxvi. p. 80; and FRANCIS DE CASTELNAU: Expedition dans les Parties Centrales de l'Amérique du Sud, 5me Partie, Géographie, planches v. vii. and viii.

borders of Paraguay to Eastern Patagonia, a country which, itself a plain, continues the almost uniformly level surface to the southern extremity of the continent. These Pampas are distinguished from the more northern plains by the scarcity of rain, and the long droughts to which they are subjected: far inland, indeed, near the mountains, and where they march on Bolivia, few years pass without heavy rains and inundations, which convert large districts into lake, swamp, or bog; and the country is so flat, that the rivers are not only unable to carry off the volumes of water which fall on the plains or descend from the higher ground, but occasionally when the rain-fall has been heavier, or has commenced much earlier nearer the mouths of the rivers than further inland, the course of the streams is apparently reversed, and for a short time they run up.* The rain that falls on the southern plains is comparatively slight, and though sufficient, in ordinary seasons, for the grass or thistles which grow luxuriantly, years in which there is no rain at all are by no means very uncommon. Mr. Darwin, comparing the dates of all the dry seasons about which he could get any exact information, estimates the period at which the droughts recur at about fifteen years, but they sometimes extend continuously over many seasons. The great drought that had occurred shortly before Mr. Darwin's visit to the country lasted for four or five years. "During this time," he says, "so little rain fell that the vegetation, even to the thistles, failed. The brooks were dried up, and the whole country assumed the appearance of a dusty high road. This was especially the case in the northern part of the province of Buenos Ayres, and the southern part of Santa Fé. Very great numbers of birds, wild animals, cattle, and horses perished from the want of food and water. The lowest

* THOMAS J. PAGE, Lieut., U. S. N.: La Plata, the Argentine Confederation and Paraguay, p. 393.

estimation of the loss of cattle, in the province of Buenos Ayres alone, was taken at one million head."*

A similar general dryness, with occasional drought, extends far to the southward, and forms one of the most strongly-marked features of the climate of Eastern Patagonia, in striking contrast to the almost continuous rains of the Falkland Islands, and the Fuegian Archipelago.

In the open ocean of the South Atlantic, between the parallel of 25° S. and the Equator, a wind from some point between south and east—which is called THE SOUTH-EAST TRADE WIND—blows almost uninterruptedly the whole year round. The SOUTH-EAST TRADE possesses many of the distinctive features of the NORTH-EAST TRADE of the North Atlantic. It is soft and pleasant, and is singularly steady both in its direction and force; but it is somewhat stronger than its northern counterpart. In the neighbourhood of St. Helena, and from that towards Ascension, it is more constant than any wind on the face of the earth. Here its direction is very nearly fixed at S.E., and from that point it blows generally right up to the Equator, and in the winter frequently to the northward of it.† At that season it stretches across the whole Atlantic, blowing home to the East Coast of South America, though its direction becomes much more easterly in the western part of the sea, and it very commonly blows on the coast of Brazil as a wind nearly east. North of the line it sweeps along the South American Coast as a wind from E.S.E., and mingles with the North-East Trade in the

* CHARLES DARWIN: Journal of Researches into the Natural History and Geology of the Countries visited during the Voyage of H.M.S. "Beagle" Round the World, under the command of Captain Fitzroy, R.N., Edit. 1852, p. 132.

† *Winter* here means the winter of the southern hemisphere. I have used the words winter and summer throughout in their strict sense according to the hemisphere under consideration.

Caribbean Sea, but at other times of the year it does not reach so far to the north ; and the North East Trade blows home to the mainland along the whole of that part of the coast.

A similar movement of its boundary takes place in mid-ocean ; in the winter of the southern hemisphere—the northern summer—the limit of the Northerly Trade is at its farthest north, and the Southerly Trade, blowing fresh across the line from the south-east, is often found as far north as 5° N. As the limit of the Northerly Trade goes south, that of the Southerly Trade also recedes, and during the southern summer rarely crosses into north latitude.

Further to the east, and near the African coast, the wind is much more southerly, often blowing from south, and frequently veering to the westward. As the latitude diminishes, the westerly tendency becomes much more marked, and crossing the line this branch of the Trade becomes in the Gulf of Guinea a wind from S.W. and W.S.W. It here frequently coalesces with the eastern branch of the Northerly Trade, and the two form a prevailing wind from between W.N.W. and W.S.W. But though westerly winds may be said to prevail, there is often absolutely no wind at all. There is scarcely any part of the ocean where calms are more frequent than the Gulf of Guinea and the coast of Africa generally, between about 10° N. and 2° or 3° S. Nor are these calms confined merely to the immediate neighbourhood of the coast. As far to the westward as the meridian of 30° W., and occasionally still further, a region intervenes between the Northerly and Southerly Trades, where the winds are at all times of the year most uncertain. In this region, westerly winds are common, but they blow, for the most part, irregularly and with fitful strength; short but exceedingly violent squalls, known as TORNADOS, are frequent ; rain falls profusely, to such an extent that it has been described as absolutely

forming pools of fresh water lying on the top of the salt; calms are extremely frequent; and puffs of wind from any point of the compass, combine to make this particular part of the ocean the most tedious to the mariner. This is what has been called by geographers and anemologists THE REGION OF EQUATORIAL CALMS, or THE ZONE OF CONSTANT PRECIPITATION, but to which our old navigators gave the more distinct and familiar name of THE RAINS, and which is commonly known by our modern seamen as THE DOLDRUMS. Varying in position, it also varies in breadth; extending sometimes through four or five degrees of latitude, at others over only a few miles; but the instances of ships passing from the Northerly Trades into the Southerly, without experiencing some of the unpleasantness of the Doldrums, are very rare. Near the African coast, however, where, as has been said, the two Trades frequently coalesce into a westerly wind, ships have occasionally passed the Doldrums without much delay or inconvenience. La Pérouse, for example, says, under date September, 1785:— "We lost the Trade in 14° N., whence as far as the line we had a constant succession of winds from West to S.W. These compelled me to keep close along the coast of Africa for about 60 leagues. We crossed the Equator on the 29th of September, in 15½° west longitude. Those sailors are quite in error who are afraid of finding calms near the line at this season. We had not a single day without wind, and had rain only once, though then, indeed, there was enough to enable us to fill twenty-five barrels."* This account, given by a navigator of the skill and experience of La Pérouse, is interesting as showing how vague and unsettled men's notions were with regard to the region of equatorial calms, even so late as the end of last century. More exact inquiry has shown that, in this part,

* Voyage de La Pérouse. 8vo. Edit., ii. 25.

it is broader and more tedious, having, as a rule, all the disagreeable peculiarities of the region in an exaggerated degree; whilst further to the west the evils diminish, and the district becomes much narrower. On this account ships of the present day, not bound to the African ports, scarcely ever attempt the eastern route; but keep well to the westward, so as to cross the line between 25° and 30° W.

The southern boundary of the South-East Trade also changes its latitude with the seasons, approaching the Equator in winter, and receding in summer; but the parallel of 25° S. is about its mean position, except in the neighbourhood of the land. On the eastern side of the ocean, the Trade wind is very commonly found as far south as 30°; and during the summer months a wind from between S. and S.E. blows with great, though not undeviating, regularity, even to the southward of the Cape of Good Hope. Leaving the Cape with this wind, homeward-bound ships stretch away at once towards the N.W., and make St. Helena in a straight course, with a fine, fair breeze the whole way; but during the winter westerly winds prevail to the southward of 30°, and ships are then, as a rule, compelled to keep near the African coast until they fall in with the Trade.

On the western side of the ocean, the Trade wind veers to the east, and often to the N.E., as it approaches the American coast. This northerly tendency is experienced most frequently during the summer; at which season, indeed, from the latitude of 10° S. it prevails with great constancy; but even in winter, when the winds from the southward of east are prevalent, they generally hold well to the east, passing occasionally to the northward; and further to the south, the northerly winds seem to predominate at all seasons.*

* HORSBURGH: East Indian Directory, i. 53—59.—ADMIRALTY: Wind

The very scanty evidence that we have of the winds in the interior of South Africa all tends to show that the south-easterly wind, which we find on the ocean, prevails also over that continent. Dr. Livingstone says that "the prevailing winds of most of the interior country are easterly with a little southing;"* and he repeatedly alludes to the continued predominance of easterly winds; but, in places at least, westerly winds, accompanied for the most part by heavy rains, would seem to be frequent during the summer, and more especially during the latter months of the summer.†

Of the winds that blow over the continent of South America we have more certain intelligence. Although we have no extended series of meteorological observations, such as the care of the United States Government, or of the numerous scientific societies, has provided for North America, the evidence of many travellers and settlers is quite sufficient to establish our knowledge of the fact that the easterly wind, which strikes the shores of Brazil, near the Equator, reaches far inland. In the woods, indeed, which so entirely cover the face of the country, there is at all times a dead calm: the air is stagnant, hot, and loaded with moisture, to an extent that can scarcely be endured; and the easterly wind, if it blows over the Selvas—as we may fairly presume it does—blows above the dense mass of foliage, without being able to penetrate into the obscure depths below.

But on the Amazon itself it is well and even strongly marked; blowing at times with a force which it scarcely ever exhibits at sea. This is more especially the case in the dry season, which, varying a month or two in begin-

and Current Charts of the Atlantic. 1868.—Board of Trade Wind Charts; South Atlantic; Coast of Brazil.

* Missionary Researches, 95.

† *Ibid*, 436.—THOMAS BAINES: Explorations in South-West Africa *passim*.

ning or ending, at different distances from the sea, extends from June to February. On the lower part of the river, "when the regular east wind blew, sailing vessels could get along very well; but when this failed, they were obliged to remain, sometimes many days together, anchored near the shore. In the dry season, from August to December, when the trade wind is strong and the currents slack, a schooner could reach the mouth of the Rio Negro, a thousand miles from Pará, in about forty days; but in the wet season, from January to July, when the east wind no longer blows, and the Amazon pours forth its full volume of water, flooding the banks, and producing a tearing current, it took three months to travel the same distance."*

Above Obydos, the dry season generally lasts from July to January; and "the drier the weather, the stronger blows the east wind."† At Santarem, "during six months of the year, from August to February, very little rain falls, and the sky is cloudless for weeks together, the fresh breezes from the sea, nearly 400 miles distant, moderating the great heat of the sun. The wind is sometimes so strong for days together that it is difficult to make way against it in walking along the streets."‡ "The trade wind blows with great force during the dry months; the hotter the weather, the stronger is the breeze; until towards the end of the season it amounts to a gale, stopping the progress of downward-bound vessels."§

During the dry season, the Trade is felt strongly as far as the mouth of the Rio Negro, or even higher, but on the upper Amazon it does not blow with the same persistent regularity: the wind is variable, seldom remaining long in the same quarter; calms are general; and the atmosphere is sultry and stagnant. In this part of the valley, too, the distinction between dry and wet seasons ceases to be clearly

* BATES: *Op. cit.* vol. i. p. 213.
† *Ibid.* i. 273.
‡ *Ibid.* ii. 21.
§ *Ibid.* ii. 21.

marked; the rains lasting much longer, and falling at frequent intervals during the dry months. Further to the westward, and towards the neighbourhood of the Andes, the climate becomes extremely wet, and the air is almost saturated with moisture. Of this Mr. Bates gives some instances, homely indeed, but as conclusive as any hygrometric measurements. At S. Paulo, he says, it was impossible to keep salt for many days in a solid state; and at Chinchao, the most refined sugar in a few days dissolved into syrup.

The change of season, from dry to wet, seems in all parts of the lower river to be ushered in with a violent storm from the west, accompanied by much thunder and lightning; and through the whole of the wet season, westerly winds are frequent, but not constant; calms, light airs, and occasional winds from the east, alternating in a very irregular manner.

To the south of the Amazon, the country is very imperfectly known, owing to the impenetrable nature of the forests with which it is covered, but there is reason to suppose that the same easterly wind, which blows on the river, blows also over the Selvas. It is, indeed, often experienced on those southern tributaries of the great stream which are of sufficient breadth to admit of it; and Mr. Bates voyaging in September, on the Tapajos, one of these tributaries, found a fresh breeze every night, from east to N.E., which, during the day, gave place to a strong wind from north or north-west.*

Still further to the south, the prevailing winds of Paraguay are from the north-east. These are warm and moist, and in summer are often accompanied by rain; and in winter it frequently rains with a southerly or south-easterly wind. Winds from west and north-west are very rare, and

* Bates: *Op. cit.* ii. 144 149.

never last long, but almost invariably veer through S.W. to south ;* but further to the south again, north-westerly, westerly, and south-westerly winds prevail, and sweep over the Pampas, occasionally with great force. Such winds frequently extend some distance to seaward, and are called PAMPEROS, winds off the Pampas, a name which properly belongs to every south-westerly wind on that coast, though European usage has confined it, for the most part, to violent westerly squalls.

In the southern part of this great basin westerly winds predominate in a very marked manner; but they are scarcely established till a higher latitude than that of the Cape of Good Hope is attained. Between the parallels of 40° and 60°, the westerly wind blows with a constancy little inferior to that of the trade, but with much greater violence. About the parallel of 50°, indeed, it is found, as a rule, to be blowing "half a gale of wind," and this not only south of the Atlantic, but all round the world. This is the wind which is so advantageous to stout-built, well-found, Australian clippers. If they are strong enough to bear the boisterous weather of the high latitudes, they are almost sure of a wind that will carry them along at the highest possible rate of sailing; and the runs of some of the English and American crack ships, in making their casting, seem scarcely credible. The celebrated clipper, "Red Jacket," for instance, on her passage from Liverpool to Melbourne in 1856, ran from 72° 26′ E., to 134° 38′ E., in eight days, being an average of 334 nautical miles (knots) a day. This was in July, the depth of winter, and the abstract of her log shows what terrible weather she had. Gales, squalls, storms, rain, snow, sleet, hail, "entire fore part of the ship covered with ice," these were the things she had to encounter; the wear and tear of the

* ALFRED M. DU GRATY, Colonel d'Artillerie: La République du Paraguay, p. 240.

ship, the risk of spars and life, was the price she had to pay for making this almost unparalleled run.* Another Liverpool clipper, the "James Baines," on the 17th June, 1854, ran from 43° 31′ S., 106° 15′ E., to 42° 47′ S., 115° 54′ E., a distance of 420 miles; and this is the abstract of her log for that day: "Winds, W. to S.W. First part, breeze freshening; at 6 P.M., wind S.W. and freshening; at 8.30 P.M., in all starboard stunsails, ship going 21 knots, with main skysail set; midnight, fresh gale and fine clear night; 8 A.M., wind and weather same; noon, less wind, attended with snow squalls."† These instances, though exceptional as runs, are by no means so in the weather; they are exceptional, merely because there are but few ships afloat of the capabilities of the "Red Jacket" or the "James Baines," or which have their masts so stayed that they could carry main-skysails under such circumstances. Very strong westerly winds are the rule, not the exception, in those high southern latitudes; and the Sailing Directions teem with instances of runs nearly as remarkable as those just spoken of, whilst, on the other hand, they give very many in which the ships had more wind than they could take advantage of. The "Terror," for example, on her passage from Boston, U.S., to Melbourne, in the winter of 1855, being "unable to carry sail on account of the weakness of the spars," had to heave-to on five different occasions; and in December, 1856, the "Robert Patten," from St. John's, N.B., to Port Adelaide, carried away successively, at a few days' interval, her main and foretop masts in a sharp westerly squall, or a fresh westerly gale.‡

Not only on account of the violence and severity of the weather, but principally on account of the extreme risk from icebergs floating out from the Antarctic incurred by

* MAURY: Sailing Directions, Eighth Edition, ii. 651.

† *Ibid.* ii. 646.

‡ *Ibid.* ii. 658, 671.

ships driven at such a speed through a night of sixteen or eighteen hours' duration, this high southerly route has, of late years, fallen into disesteem amongst navigators. The advantages it offers are held not to be worth the certain discomfort and danger; and the mysterious loss of several ships, which have probably struck on the ice and gone down with all hands, has filled with awe even the rude breasts of our seamen. The Admiralty Directory for Australia recommends ships to make their easting on or about the parallel of 39°, where the winds are less boisterous and the climate milder. Even for those who are disposed to run great risk in order to save time, it may be doubted if it is really advisable to go to the southward of the fiftieth parallel, where the winds are as strong as they are still further south, and are more steady.

The instances which have been given of the strength of these westerly winds are, for the most part, to the eastward of the Cape of Good Hope. Outward bound ships making a sweep from a position in the South Atlantic near 25° S., 30° W., and following approximately the arc of a great circle, do not get into the high latitudes, where they have the full force of the westerly winds, till they are near the longitude of the Cape; whilst ships coming home, round Cape Horn, haul to the northward as soon as they are sure of being sufficiently far to the east, and do not go any great way from the South American coast. The higher latitudes south of the Atlantic are thus not on the high road to any great commercial port, and are but rarely traversed. Captain Maury, in the earlier editions of the Sailing Directions, noted that, "among the many thousand merchant logs that are on file in the Observatory, there is not one to show that any trader has ever performed the voyage from the offings of Cape Horn to the offings of the Cape of Good Hope."* Later information

* MAURY: Sailing Directions, Eighth Edition, ii. 795.

has led him to recommend, more positively than he at first felt authorized to do, that route for ships going to India or China from Valparaiso or Callao. Calcutta, indeed, is about 2,500 miles nearer that way than going west, across the Pacific; and though Canton is about a thousand miles further, he considers that the saving in time, due to the strong westerly winds, would more than compensate for an even greater excess of distance.

Cape Horn itself, and the whole neighbouring part of the ocean, has an evil fame amongst sailors for the severity of its westerly and south-westerly gales,* gales which blow with very great frequency and violence on the coasts of the Falkland Islands. Captain (the late Admiral) Fitzroy says that there "the prevalent direction of the wind is westerly. Gales, in general, commence in the N.W., and draw or fly round to the S.W.; and it may be remarked, that when rain accompanies a N.W. wind, it soon shifts into the S.W. quarter, and blows hard; N.E. and northerly winds bring gloomy, overcast weather, with much rain. South-easterly winds also bring much rain: they are not frequent, but they blow hard, and as the gale increases, it hauls southward. Gales of wind, as well as squalls, are more sudden and blow more furiously from the southern quarter, between S.W. and S.E., than from other directions. Wind from east is rarely lasting or strong; it generally brings fine weather, and may be expected in April, May, June, and July, rather than at other times; but intervals of fine weather (short indeed), with light breezes from E.S.E. to E.N.E., occur occasionally throughout the year."†

In the South Atlantic these westerly winds, as I have

* KING AND FITZROY: Narrative of the Surveying Voyages of His Majesty's ships "Adventure" and "Beagle," between the Years 1826 and 1836, *passim*.

† *Ibid.* ii. 244.

already said, cannot be considered as firmly established north of the parallel of 40° S., although they are often met with in a lower latitude; as, for instance, at the Cape of Good Hope, in latitude 34° S., where the violence of the westerly gales of winter is a matter of notoriety. Even in that neighbourhood, however, and on the meridian of the Cape, they are much more common further to the south. According to the latest Admiralty chart, from the meridian of Port Natal to 16° E. in the usual track of homeward-bound ships, the ratio of winter gales to summer is as 3 to 1; of westerly gales to easterly as 13·5 to 1; and, on the other hand, for—

| | |
|---|---|
| 1 gale that blows between .. ... | 33° and 34° S. |
| 1·3 gales blow between ..... | 34° and 35° |
| 1·8 gales blow between ..... | 35° and 36°, and |
| 2·7 gales blow between ..... | 36° and 37° S. |

In summer, in fact, a branch of the south-east trade reaches out very commonly quite as far south as the Cape; a branch which in winter recedes somewhat towards the tropic, thus giving place to the westerly winds, which prevail the year round in the higher latitudes.

Between the trade and the westerly winds, on the one hand; between the southerly wind of the African coast and the northerly wind of the Brazilian on the other, there is a large patch where the winds are very variable, and where calms and gales are common. This region is of considerable extent, and alters its position somewhat with the change of season; but its worst peculiarities are generally to be found between 27° and 37° S., and between 0° and 15° W. Across this wearisome region, most of the outward-bound East India, China, and Australian ships pass; suffering often a delay which is equivalent to lengthening their voyage by two or three days. Captain Cook says, October 6, 1776: "Being then in the latitude of 35° 15′ S., longitude 7° 45′ W., we met with light airs

and calms by turns, for three days successively." The "James Baines," in her passage of 1854, already referred to, experienced here a tremendous gale from the south-east, veering to south-west,* which lasted about three days; whilst the "Red Jacket," in this neighbourhood, had calms and light baffling winds. Almost all the abstracts of logs given by Captain Maury, in the Sailing Directions, show the same—viz., that ships in crossing this patch suffer either from gales, calms, or light variable winds; so that, notwithstanding it lies in the direct course, it might be a question whether distance in time could not be shortened by lengthening the distance in miles, and standing further to the southward, before commencing, in earnest, to make the easting. When a ship is in about 25° S., 30° W., she very commonly keeps an average course by which she crosses the prime meridian at about 35° S., thus passing through the whole breadth of this region of calms, gales, and variables; whereas, if from the same point of departure she were to steer a more southerly course, so as not to cross the prime meridian much to the northward of 45° S., this tedious locality would be, to a great extent, avoided, and time probably gained, notwithstanding the additional number of miles sailed over. The best illustration of this is, perhaps, to be found in the comparison of the routes of the "Red Jacket" in June, and the "Flying Dutchman" in November, 1854. The ships were both

* Abstract log of "James Baines:" May 23.—Lat. 39° 45′ S.; long. 6° 39′ W.; winds, S.E. Commences with increasing breeze, and eastern sky very red. At 4 p.m. every sail off the ship but foresail; blowing a heavy gale and confused sea from S.W. Midnight, wind and weather the same. At 8 a.m., wore ship to northward and eastward; heavy squalls and rain. Noon, wind and weather the same.——May 24.—Lat. 38° 22′ S., long. 3° 14′ W.; winds, S.S.E. to S.S.W. Commences with heavy gales, with squalls of rain. Midnight, the same. 8 a.m., still increasing; weather thick. Noon, weather thick, and squalls very heavy.—Sailing Directions, ii. 644.

celebrated amongst fast-sailing clippers; the "Red Jacket," in particular, was supposed to be one of the fastest afloat; and yet, from an approximate position, 25° S., 30° W., to 47° S., 33° E., she was beaten by the "Flying Dutchman" by nearly *two* days; and this in one of the quickest runs on record. The difference in the time of year does not appear, by a comparison of the logs for the whole year, as given in the Sailing Directions, to be of any consequence; in fact, the log of the "Terror," for the same month as the "Red Jacket," represents her as having, by the westerly and southerly route, at this part of her voyage, had a succession of fair winds which she was unable to take advantage of; thus her time is longer than the "Red Jacket's;" but the contrast of the weather which the two ships experienced is remarkable.

This region of calms frequently stretches out very far to the westward and northward; it is not unusual for its peculiar weather to be found as far as 25° W., and sometimes even as far as 30° W.; but it appears to extend beyond that only in rare instances, when it also reaches farther than usual towards the north, being experienced at times as far north as 15° S. in that western part. The patch thus forms a sort of irregular ellipse, the major axis of which lies nearly N.W. and S.E.; and in it, as has been said, calms and heavy gales are very frequent; winds blow, in apparent caprice, from every possible quarter; and the weather is most commonly such as the navigator would seek to avoid.

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## SECTION IV.

### The Basin of the North Pacific.

The Basin of the North Pacific may be defined as extending from the great mountain chain of North America,

westward, to the Highlands of Central Asia, or, further south, to the Malay Peninsula. It thus contains all that part of the continent of North America which lies to the west of the mountains; and, on the west, all the lower or eastern part of the Chinese Empire.

Near the Asiatic coast, a chain of mountainous islands—the islands of Japan, Formosa, the Philippine Islands—reaching into the Indian Archipelago and to the equator, seems to form a partial boundary on the west; but this chain is so broken, the islands and the mountains are so frequently separated by such wide intervals, that they cannot be considered as shutting out from the Pacific the large sea, and the vast tract of low-lying land to the westward, or as forming a barrier sufficiently absolute to prevent a very free passage of atmospheric currents. We do not, in fact, find such a barrier until, in the far west of China and in Thibet, the land attains a very great elevation, and, abutting on the Eastern Himalaya, stretches from that away to the northward in a series of lofty and almost uninterrupted mountain ranges.

The eastern part of China appears to be, as a rule, low lying and flat. Not that it has no hills or mountains: on the contrary, it has several, some of which reach to a height of nearly 5,000 feet; but such are exceptional, and the ranges of which they form part are insignificant, and have been more especially noticed by travellers rather in consequence of their picturesque appearance, and the contrast to the general level of the country, than on account of any claim which their size would give them. The long distance to which the Yang-tsze-kiang is navigable, even for ships of great burden, is a convincing proof of the very gradual nature of the rise from east to west. In the winter of 1858, when the river was at its lowest, the "Furious," a paddle-wheel steam-frigate, of 1,287 tons, went up as far as Hankow, 600 miles from the sea; and the two rivers

which meet there at right angles to each other are both highways of native commerce far beyond that point.*

The Great Canal, on the other hand, crossing the Hoang-ho and Yang-tsze-kiang, runs from north to south for about 700 miles; and "in every part of its course it passes through alluvial soil, readily penetrated by the tools of workmen, and is intersected by numerous streams. It would be difficult to find any part of it carried through twenty miles of country unaided by tributary rivers. It is neither carried through any mountain nor over any valley. In all that space there were neither hills, quarries, nor rocks, which gave the workmen any trouble either to level or penetrate." †

On the east, there is but small space between the shore and the mountains which form, as it were, the backbone of North America; and this space is, for the most part, an ascent to the mountain ranges, either by gentle slopes, by graduated terraces, or by a series of lower ranges which rise one behind the other in a wildly picturesque manner. But the principal ranges, knitted one into the other, are, on this side, a most unmistakeable boundary for the basin; there are, indeed, occasional gaps in the mountain chain; gaps which permit of very remarkable local peculiarities in the atmospheric currents; but these gaps, absolutely small, are utterly insignificant in proportion to the enormous length of the coast line; and the barrier may, in general terms, be spoken of as impervious.

Across nearly the whole of the North Pacific Ocean, between the equator and the parallel of 20° N. there is generally

* LAURENCE OLIPHANT: Narrative of the Earl of Elgin's Mission to China and Japan, vol. ii. p. 397. — Lieut.-Col. SAREL: Notes on the Yang-tsze-kiang, etc., in the Journal of the Royal Geographical Society, vol. xxxii.

† Sir J. F. DAVIS: China; Edit. 1857, i. 188.

found a wind from a direction varying between north and east. This wind, from its soft, mild nature, and its striking resemblance to the wind found in the same latitudes of the Atlantic, has been, from the earliest ages, known as the NORTH-EAST TRADE WIND. It is, however, by no means so strong or steady as the trade wind of the Atlantic; its limits are narrower, and its direction is more easterly, inclining at times even to the south of east. This is more particularly the case in the summer, towards the western part of the ocean; so that Horsburgh advises ships bound from China to South America or Australia, when they have got clear of the islands, not to attempt to make any more easting in crossing the north-east Trade, which, he says, "often hangs between E. by N. and E. by S."*

But, in fact, at that season, in the neighbourhood of the Philippine Islands, the prevailing direction of the trade wind is so southerly that ships are often compelled to stand to the east, on the starboard tack, for several degrees, before they find the wind sufficiently easterly to enable them to lay a southerly course.†

In the Formosa Channel, and in the northern part of the China Sea, the wind during the entire summer prevails from the south-west. Further south, the wind is more southerly, and below the parallel of about 18° N. draws round frequently to the east of south; but with these slight changes in direction, a wind, decidedly from the south, and extending from the equator as far as 30° N. generally commences about the beginning of May. It is a warm, moist wind, frequently accompanied by heavy rain; but though it blows with great regularity, it is seldom strong, and is at times interrupted by dangerous squalls and hard gales from various quarters.

Late in the season, in August, September, or October,

* HORSBURGH: East India Directory, ii. 612.

† Board of Trade Charts: Western Part of the North Pacific Ocean.

storms of an extreme fury, and producing the most disastrous effects, are not uncommon. Scarcely a season passes in which their terrible violence is not fatally felt in the China Sea, or on some of the southern parts of the China coast. These storms, which are known by the local name of TYPHOONS,* appear to resemble, in their peculiar character, the hurricanes of the West Indies already spoken of. They are distinguished, like them, by the rapid and sudden changes in the direction of the wind; often by a short lull, preceding a fresh burst of the storm; by the storm wave, and, above all, by the extreme force of the wind. Their range, however, is not so wide; they are unknown to the southward of 10° N., and are comparatively rare to the northward of 23° or 24° N., though they are occasionally experienced as far north as Shanghai, or the coast of Japan.

During October, the wind in the China Seas is for the most part very unsettled: a typhoon is always to be dreaded; but even if the month should pass without one, the weather is bad. Towards the end it becomes better; and by the beginning of November, the wind having changed through sixteen points, settles down into a strong, steady breeze at N.E., the sky being generally clear and the weather fine. This north-easterly wind, which blows through the channel of Formosa—generally considerably to the northward, often for some distance to the eastward of the island of that name—with the fine weather which accompanies it, continues through the winter, and till April. Its strength then gradually decreases; it alternates with

* The word *Typhoon* is undoubtedly Chinese. It is the name in familiar use among the boatmen of Hong Kong, Macao, and the Canton River generally; and is written by our Chinese scholars *Tai-foong, a great wind.* The resemblance to the Greek Τυφῶν is merely accidental; and it is just as likely to be derived from it, as is Canton (Kwang-tung) from the French *canton*, and not a whit more likely.

breezes from the southward, and by the beginning of May it gives place altogether to the south-westerly wind of the summer.

These north-easterly and south-westerly winds, thus changing with the seasons, are known as the MONSOONS ;* they are distinguished as the north-east and the south-west monsoons ; as the winter and summer ; or as the dry and wet. The winds are so regular, and the changes so certain that all nautical affairs—the disposition of men-of-war, the arrival or departure of merchant ships—are arranged, as far as possible, to suit the prevailing monsoon. The Chinese follow the same rule ; and every winter, their huge, clumsy craft, with forecastles and sterncastles rising high into the air, resembling nothing so much as the old pictures of the *Harry, Grace à Dieu*, may be seen in Hong Kong Roadstead, where they touch on their way from the north to Siam, whence they purpose to return during the following summer.

Towards the American coast, the Trade wind extends much further to the north than it does in mid ocean: it is also more northerly in its direction, coming round often to north, and even to the west of north. On the coast of California, from the latitude of 40° N. southwards, for ten or fifteen degrees, a wind from N.W., or nearly parallel to the coast, blows pretty steadily during the greater part of the year. This northerly wind tempers the summer heat so much, that on shore, even in August, fires are frequently necessary for comfort. Houses are built facing the south, in order to avoid the cold blast, which, for nearly nine months out of the twelve, comes off the sea ; but during its continuance there is seldom any rain, though a dense fog is common: the fresh breeze sweeps away the mist as it forms, without allowing it time to turn into rain.

* A name derived from a Persian word, which in English characters is generally written *Mousum, a season.*

The air, however, rapidly becomes warm as it passes over the land, and in the interior of the country attains a high temperature.

During the winter months, this north-westerly wind is not found quite so far to the northward; but it stretches down the coast at that season, often nearly to the line, and pretty constantly as far as 10° or 15° N. In summer, on the other hand, it gives place, in the lower latitudes, to a south-westerly or southerly wind. At Mazatlan and San Blas, for instance, the southerly wind begins in June and ends in October; like the southerly monsoon on the coast of China, it is accompanied by much rain, does not blow steadily, is interrupted by frequent squalls from different points of the compass, and generally winds up with a violent and dangerous storm. As this storm, which is always from between S.E. and S.W., most commonly happens about the festival of St. Francis, the 5th of October, it has received the local name of the *Cordonazo de San Francisco,* the lash of St. Francis: but it is, sometimes at least, considerably later; and does the more damage, coming when the danger is no longer apprehended. Thus, in 1839, it did not come till the 1st of November, when twelve vessels, lying at Mazatlan, were lost with all hands.*

These alternating winds, on the west coast of Mexico—from the North or N.W. through the winter; from between S.W. and S.E. through the summer—are occasionally spoken of as the MEXICAN MONSOONS—a name which has been adapted to them on account of their changing with the seasons, in a way somewhat similar to the MONSOONS properly so called. It is, however, a name to be found in books, rather than in common use.

To the northward of 40° N, the mean direction of the

* M. DUFLOT DE MOFRAS: Exploration du Territoire de l'Oregon, etc., 1844, vol. i. pp. 169, 403; vol. ii. pp. 16, 48, 54.

winds for the whole year is about due west; inclining to the north of west during the summer, and to the south of west during the winter months. These westerly winds stretch back the whole way across the Pacific; and when well clear of the American coast, extend from the parallel of 30° N. to the farthest north. They are felt in Japan, on the one side, and in the once Russian Provinces of North America on the other; and prevailing from the south-west, as they do throughout the winter, they form a current of soft warm air to which Vancouver's Island and the adjacent coasts owe the mildness of their climate. The Spaniards, from the very earliest period of Pacific navigation, became acquainted with the regularity of these westerly winds, and in consequence moved the depôt of their trade with the Philippine Islands from Callao, where it was established, to Acapulco, a port more convenient to ships returning by high northern latitudes. So early as the year 1587, Cavendish met, and, after a sharp engagement, took the Acapulco ship, on her homeward passage, several degrees to the northward of her port, on the coast of California.

Between the westerly winds and the easterly or Trade wind, there is an intermediate region where the wind has no very settled direction. This may be considered as lying for the most part between the parallels of 20° and 30° N. In the summer, the Trade wind extends somewhat further to the north. In the winter the westerly wind is found further to the south; but at all seasons there is, between the two, a space where the wind cannot be, in any degree, relied on—where winds from opposite quarters, sharp squalls or calms, alternate in the most baffling succession On this account ships going east or west should avoid trying to change their longitude between these parallels, but should keep to the northward or southward of these limits, where they can almost count on

having a fresh fair wind. Ignorant of this, La Pérouse, in November, 1786, having gone south as far as 20° N., in search of the Trade wind to help him on his way from San Francisco to the Coast of China, crossed on that parallel: for the whole way, through nearly seventy degrees of longitude, he had a succession of winds which changed every few hours. "The winds from N.W.," he says, "which caused a heavy swell, veered through north to N.E., and the weather became clear and fine. Before long they shifted to south and S.E., the sky became overcast, and it rained heavily. A few hours later, the wind would go round to the S.W., then to west, and so back again to N.W., the horizon at the same time becoming clear. This rotation lasted for three or four days, and on no occasion did the wind back from S.E. to E. and N.E."*

Cook, and other distinguished navigators, found the same unsettled weather on the parallel of 20° N., and learnt by degrees, that, in winter at least, it was not advisable to cross to the westward much to the north of the parallel of 13°, where the Trade is both fresh and steady.

It will be noticed, however, that this unsettled region does not extend across the Pacific Ocean, from shore to shore. On the east, near the American coast, the northerly winds are felt far to seaward, for a distance which is, perhaps, on the average, not less than ten or twelve degrees of longitude. On the west, the alternation of the monsoons is clearly marked as far north as the parallel of 30° N., and reaches, without any decided break, into the line of the prevailing west winds.

There can be little doubt that the monsoons are experienced all over the southern and eastern parts of China. Limited as is our acquaintance with the interior of the Celestial Empire, we still know that the north-easterly

* Voyage de La Pérouse: 8vo. Edit., 1798, ii. 340.

wind prevails on the Yang-tsze-kiang during the winter, and that the level of the river is then more than fifty feet below the high-water mark.* The jealous care with which the Chinese have excluded Europeans from their territory, and more especially from Upper Thibet, renders it at present impossible to speak with any certainty as to the exact causes of the rise of the river in the summer, but the known dryness of the air in Thibet, the great height of the snow-line on the northern slope of the Himalayas—a height considerably exceeding that on the southern side—and the want of evidence that snow, even in winter, lies to any great depth on those elevated plains, seem to render it most probable that there is no melting of snow in summer sufficient to account for such a rise in the Yang-tsze-kiang, and that this rise is principally due to heavy rains accompanying the south-west monsoon.

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## SECTION V.

### THE BASIN OF THE SOUTH PACIFIC.

THE Basin of the South Pacific is bounded on the east by the Andes; it extends across the Pacific to Australia, the large islands which lie immediately to the north of it—New Guinea, Celebes, and Borneo—and the numberless small ones, which are usually comprised under the general name of the Indian Archipelago.

Along the eastern coast of Australia, run successive ranges of mountains, which, though they are by no means of an altitude to compare with that of the mountains of South America, attain in many places to a very considerable height. The Australian Alps, in the south-eastern part of the continent, reach beyond the line of perpetual

* OLIPHANT: China and Japan, ii. 377.

snow, and further north, the Blue Mountains and other ranges, form a barrier of from three to five thousand feet above the sea. Daily custom, and the well-beaten highways which now traverse the mountain passes, make light of the obstacles which separate the eastern from the western counties of New South Wales, but their importance in physical geography can be better estimated by recalling the sentiments of the early settlers. It was not "until a succession of untoward seasons, and the rapid increase of their stock pointed out to them the necessity of seeking for more extensive pasturage, that they contemplated surmounting that dark and rugged chain of mountains, which, like the natural ramparts of Spain and Italy, rose high over the nether forest, and broke the line of the western horizon. A Mr. Caley is said to have been the first who attempted to scale the Blue Mountains; but he did not long persevere in struggling with difficulties too great for ordinary resolution to overcome. It appears that he retraced his steps, after having penetrated about sixteen miles into their dark and precipitous recesses; and a heap of stones which the traveller passes about that distance from Erne Ford, on the road to Bathurst, marks the extreme point reached by the first expedition to the westward of the Nepean River."* The Queensland ranges are of the same wild and rugged nature, prolonging the high and difficult boundary line nearly as far north as Cape York,† and between these and the sea, there is but a narrow strip of land, seldom more than fifty or sixty miles, and often not nearly so much. The mountain district itself extends over a much greater breadth; ranges rising behind ranges, and holding between them those elevated

* Captain CHARLES STURT, 39th Regiment: Two Expeditions into the Interior of Southern Australia, vol. i. p. 73.

† Dr. LUDWIG LEICHHARDT: Overland Expedition in Australia from Moreton Bay to Port Essington, p. 42, and *passim*.

plains, which have been the basis of the pastoral wealth of Eastern Australia, or those deeper valleys which, by their mineral treasures, have attracted so many thousands from all quarters of the world.

Both on its eastern and western sides, the Basin of the South Pacific is thus confined almost to the limits of the Ocean; for the Andes also approach very near to the coast line, and though the culminating points of those stupendous ridges are more distant from it than are those of the lower mountains of Australia, the lowland is little if any broader, being restricted by inferior ranges, which are not distinguished only because they have elevations, so far beyond comparison, immediately behind them.

In the South Pacific Ocean, the wind which is called THE TRADE, or the SOUTH-EAST TRADE, blows in nearly the same latitudes as the trade wind of the South Atlantic,—that is to say, between the parallel of 25° S. and the Equator. It is, however, much more easterly in its direction: in fact, notwithstanding its name, it blows in mid-ocean, more fixedly from east than from any other quarter, and quite as often from some point to the northward of east, as from a point to the southward. Between the meridians of 150° and 165° W., north of the parallel of 15° S., the trade blows freshly from between N.E. and S.E., at all seasons of the year; but further to the west, it is far from having the steadiness that distinguishes the Trade winds of other parts of the world. It blows, indeed, with tolerable regularity during the winter; but during the summer months it often gives place to the westerly wind, which is sometimes steady, though more generally very gusty: squalls, hard gales, and heavy rain are not uncommon at this season: disagreeable weather which, in December and January, extends as far south as the tropic of Capricorn.*

* FITZROY: Voyage of the "Beagle," ii. 652.

And even between the meridians where the Trade is, as a rule, steady, it is occasionally interrupted: amongst the low lagoon islands, known as the Low, or Dangerous Archipelago, in lat. 17°—22° S., long. 135°—139° W., the easterly wind often fails, and heavy squalls come from the opposite direction. "This is especially the case from November to March."* And at Tahiti from the latter end of December to the beginning of March, cloudy weather, with much rain and westerly wind, is common.†

La Pérouse's account of his experience of this summer reversion of the Trade is interesting, as illustrating the more general notices given by later explorers. In December, 1787, he says: "The night succeeding our departure from Traitor's Island was a terrible one: the wind shifted to the west, and blew very hard, with a great deal of rain. As we could not see the distance of a league from the ship at sunset, I lay-to, with the ship's head to the S.S.W., till day, when the wind still continued to blow hard from the west, and the rain fell in abundance.

"The north-north-west winds attended us beyond the Friendly Islands. They were always rainy, and often as strong as the westerly winds on the coast of Brittany in winter. We knew very well that it was the season of storms and hurricanes, but we did not expect to find the weather so constantly bad."‡ After a fortnight of westerly gales, he was becalmed for three days in sight of the Island of Pylstaart, and under date 6th January, 1788, writes: "We looked out most impatiently for the south-east breezes, which we hoped to find here, and which were to speed us to New Holland. Since the 17th of December the winds had constantly blown from the westward, and whether

* FITZROY: Voyage of the "Beagle," ii. 506.

† *Ibid.* ii. 518.—WILKES: United States' Exploring Expedition, i. 310; ii. 40; iii. 321.

‡ Voyage de La Pérouse, iii. 291.

strong or light, varied in direction only between N.W. and S.W. The trade winds, it appears, are by no means steady in these seas."*

The irregularity in the Trade of the South Pacific, which is experienced in mid-ocean, is found also in the neighbourhood of the Australian coast. The wind is not constant at any season of the year; and though the prevailing direction, within the tropics, is easterly, westerly winds are neither exceptional nor uncommon. When the Trade does blow home to the coast, in summer, it does so mostly as a north-easterly wind; and at that season, north-easterly winds predominate the whole length of the eastern coast.

Dr. Leichhardt, in his journey from Moreton Bay to the Isaacs, in the months of December and January, "experienced, with but few exceptions, during the day a cooling breeze from the north and north-east. The thunderstorms came principally from the south-west, west, and north-west; but generally showed an inclination to veer round to the northward."† By night, he seems to have had the wind commonly more from the east, or southward of east, frequently blowing strong, with a clear sky. South of the tropic, at stations on the coast of New South Wales, and Tasmania, the proportion of northerly winds to southerly, during the summer, is about 2 to 1; and the proportion of winds included between N. and S.E., easterly, to all others is very nearly 4 to 1, or 80 out of 100.‡

During the summer months, the whole of this extra-tropical coast is occasionally subject to a strong wind from the north-west, which is exceedingly hot, and is known distinctively as a Hot Wind. This is generally loaded with dust. Count Strzelecki mentions that on one occasion, coming from New Zealand, he was for two days

* Voyage de La Pérouse, iii. 307. † Overland Expedition, 154.

‡ P. E. De Strzelecki: Physical Description of New South Wales, 1845, p. 166.

prevented making Port Jackson, by the violence of a hot wind; and that although sixty miles from shore the heat exceeded 90°, and the ship's sails "were covered with a quantity of impalpable dust, which was at first mistaken for ashes, but on examination proved to be a sand." On shore, similar dust flies in clouds dense enough to veil the direct action of the sun in a very marked manner; in New South Wales, the exposed thermometer, with blackened bulb, sank during a hot wind, from 145°, at which it previously stood, to 120°; whilst at the same time, the thermometer in the shade rose from 79° to 117°.

Its great dryness is as marked a characteristic as its high temperature. The quantity of water evaporated by it was found to be about four times the quantity evaporated in the same time, from the same dish, under ordinary circumstances: and its parching effects on vegetation are most destructive. "The red and blue grape commonly lose their colour and their watery elements: the green leaves turn yellow and wither: the quality of the crops is generally deteriorated: and whole fields of most promising wheat and potatoes are often laid waste."*

Fortunately it is never of long continuance, two or three days being its extreme duration. As it ends, the wind almost invariably chops round suddenly to the southward, and blows a hard gale. The change is so sudden that "the thermometer at Port Jackson has been known to fall from 100° to 64° in less than half-an-hour."† I have a special note of its having fallen from 97° to 35° between six and ten o'clock in the evening. This southerly wind was, some few years since, commonly known at Sidney as a BRICKFIELDER, from the fact of its bringing in the stench of the brickfields which lay to the south of the town.

* STRZELECKI: New South Wales, 172, *et seq.*

† HORSBURGH: ii. 862.—Capt. PHILLIP P. KING, R.N.: Survey of the Coasts of Australia, ii. 248.

These brickfields are now, I believe, built over, and the wind has the colonial name of a *Southerly-buster.*

Along the whole eastern coast of Australia, southerly winds prevail during the winter months. South of the tropic, on the coast of New South Wales, these have, for the most part, a westerly tendency; but further north, they may be considered as merging in the Trade wind, which at that season is tolerably steady from the south-east, becoming more easterly as it approaches the Line, so that it blows through Torres Straits from nearly due east.*

To the southward are the westerly winds, which, as I have already said, blow all round the globe in the higher southern latitudes. These winds sweep along the south coast of Australia and Tasmania, blowing through Bass's Straits with a concentrated strength that has given that passage the local name of the Funnel: still further south they blow with their full force: and to the eastward, on towards Cape Horn, are perhaps stronger than anywhere else. It is of these winds that the homeward-bound Australian ships now take advantage, a measure first insisted on by Captain Maury, after a full examination into the records of great numbers of passages; although, in a careless and unpractical sort of way, their prevalence had been known for many years before. It is a voyage that tries ship and crew; but of all the voyages in the world, it is, perhaps, the most speedy for canvas.† Nevertheless, in this, as in the outward voyage round the Cape of Good Hope, seamen and shipowners have become painfully alive to the fact that it does not pay to incur the dangers of very high latitudes: and notwithstanding the shortening of the distance, and the increased strength of

* STRZELECKI: *Op. cit.*, 166.—KING: *Op. cit.*, ii. 258.—RATTRAY: On the Physical Geography, etc., of Somerset and the Cape York Peninsula; in Journal of the Royal Geographical Society, xxxviii. 384.

† MAURY: Sailing Directions, ii. 799.

the winds, ships are now, for the most part, content to keep in moderate latitudes, and to shave close past Cape Horn. But a notice of a passage made in 1853, by the American clipper, "Sovereign of the Seas," from Honolulu to New York will illustrate what may be done by exceptional ships that will venture on the very dangerous route. On March 9, she fell in with the westerly wind in 48° S., 156° W., and ran to 50° S., 47° W., by March 25. In the course of the run she had throughout a westerly gale, which carried her 4,505 nautical miles in sixteen days, during the first twelve of which she averaged 311 miles a-day; and on one day actually made 411 miles.*

These westerly winds blow home to all the southern coast of South America. Western Patagonia and Tierra del Fuego seldom experience any other than these, which come to them laden with all the moisture they have acquired in their long sea passage, and make these countries the wettest in the world. "The climate of Western Patagonia," says Admiral Fitzroy, "is so disagreeable, that the country is almost uninhabitable. Clouds, wind, and rain are continual in their annoyance. Perhaps there are not ten days in the year on which rain does not fall, and not thirty on which the wind does not blow strongly; yet the air is mild, and the temperature surprisingly uniform throughout the year. The country is like the worst part of Tierra del Fuego—a range of mountains, half sunk in ocean, barren to seaward, impenetrably wooded towards the mainland, and always drenched with the waters of frequent rain, which are never dried up by evaporation before fresh showers fall." †

The fury of the westerly gales on the coast of Tierra del Fuego, and off Cape Horn, is well known: these are, for the most part, between south and west; and the worst

* MAURY: Sailing Directions, ii. 804.

† Voyage of "Adventure" and "Beagle," ii. 142.

seem to begin from the north-west, veering to the south-west, and increasing in violence as they get more southerly. Further south, the gales are not so strong; and ships bound westward, by going almost to the parallel of 60° S., avoid the very great and almost irresistible force of the wind, and of the mountainous waves raised by it.*

On the coasts of Chili, fresh southerly winds prevail during the summer months: their direction varies between south and S.W., and a wind from any other quarter is very exceptional. During this season the weather is fine, and the sky clear; but about the end of March, northerly winds set in, bringing with them fog, rain, and storm, and continue till the end of the winter.†

Further north, the duration of the southerly wind increases; between the parallels of 35° and 25° S., they prevail from September to May, during which time the sky is clear, the weather lovely, and the climate delightful, the southerly wind tempering the summer heat. The three winter months are more unsettled, calms and northerly winds, with fog and rain, being not unfrequent.

Still further to the north, southerly and south-westerly winds prevail, with greater or less force, during the whole year; these bring in vapour from the intertropical sea, which hangs over the lowlands of Peru, like a veil of mist, but which scarcely ever falls as rain: the continued breeze seems to waft it on to the interior before it has time to condense; but inland, on the mountain side, the precipitation is very considerable. These southerly winds are, for the most part, very light, more particularly in summer, when they frequently die away altogether for two or three days at a time; but winds from the north are very rare, though they do sometimes blow in the winter months,

* Voyage of "Adventure" and "Beagle," App. 311.—Anson's Voyage Round the World, chap. viii.—MAURY: Sailing Directions, ii. 472.

† Voyage of "Adventure" and "Beagle," App. 183.

bringing with them dense fog and dark lowering weather.

These gentle winds from the south most commonly cross the Line, and sluggishly reach as far as 10° N.; or, in the months of the northern summer, much farther, becoming merged in the southerly wind which blows at that season on the west coast of Mexico. As they reach the coast, and the highlands behind it, they throw down the moisture which they have gathered in their long course over a tropical sea; and the deluging rains peculiar to those parts are the immediate consequence. At Acapulco, for instance—where, immediately behind the town, there is a range of mountains 3,000 feet high, backed by the huge mass of Popocatepetl, nearly 18,000 feet high—the fall of rain during the summer is enormous, 28 inches having been frequently registered as falling in the twenty-four hours.*

At the same season, this south-westerly wind blows over the Isthmus of Panama, the mountains of which are by no means continuous, but—as recent explorations have fully determined—are separated by wide, low-lying districts, across which the wind can freely pass. The highest point on the Panama railway is only 263 feet above the mean level of the sea; west of Lake Nicaragua, the culminating point is 141 feet above the Pacific, and but 13 feet above the lake, which has been reached by steamers and boats from San Juan; and there are several other places which have been surveyed, with a view to connect the two oceans either by railway or canal, where the elevation of the land is scarcely more considerable.† Thus the wind can pass more or less freely from one side of the isthmus to the other; and thus in the summer months

* Admiral Sir E. BELCHER: Voyage round the World, vol. i. p. 151.

† Captain BEDFORD PIM, R.N.: The Gate of the Pacific, p. 201 and *passim*.

the south-westerly winds blow from the Pacific on to the coasts adjoining Carthagena, bringing with them those heavy rains which have given Carthagena, Chagres, and Porto Bello such an evil repute. In the winter, on the other hand, as the southerly winds of the Pacific recede towards the Line, the violent Northers of the Gulf of Mexico, or of the Caribbean Sea, frequently cross the isthmus, and blow in sharp squalls on the western side—squalls which, from the places where they are most common and violent, have the local names of PAPAGAYOS and TEHUANTEPECERS.

This alternation of winds with the seasons, and the interchange which, in a more or less marked manner, is constantly going on between the two oceans, render the part of the Pacific near Central America one of the most disagreeable in the whole world to the navigator. To the east of the meridian of 85° W., and north of the Line, no dependence can be placed on the weather. Winds from all quarters, and calms, are very common; and though we know that, at the different seasons. the winds prevail from certain directions, still, the interruptions are so frequent, and apparently so capricious, that the knowledge is of very little practical use.

The westerly winds which prevail in the high latitudes of the South Pacific, and in the Southern Ocean, cannot be considered as at all established north of the parallel of 40° S. They are, indeed, often met with further north, more especially in winter, but without the fixedness or uniform strength which they have to the southward. Easterly winds, and, indeed, winds from all quarters, are often experienced; and between the parallels of 35° and 20° S. the weather is extremely variable. Knowing this, ships going east or west naturally avoid these latitudes, and run down their longitude, either to the north in the Trade, or to the southward in the westerly winds. Com-

paratively little is thus known of the immense tract that stretches across the Pacific between these parallels; but there is, nevertheless, quite sufficient evidence to show that the wind there is extremely unsettled, both in direction and force; and that both gales and calms are disagreeably frequent. This uncertain weather, however, does not extend absolutely the whole way across the Pacific; but on the eastern and western boundaries are found the winds which have been already described as prevailing in the neighbourhood of the coasts of South America and Australia.

## SECTION VI.

### The Basin of the North Indian Ocean.

The Basin of the North Indian Ocean is bounded on the east by Burmah, Siam, the Malay Peninsula, and Sumatra; on the west by the mountain chains and highlands of Eastern Africa. These highlands are of very considerable elevation, and the mountains which rise from them reach to heights varying between ten and fifteen thousand feet. The great lake, Victoria Nyanza, is nearly 4,000 feet above the sea, and between it and the eastern coast is the watershed of the rivers that flow east and west, to fall into the sea on the one hand, or into the lake and the Nile on the other. This watershed stretches away northward to the mountains of Abyssinia, amongst which, at very great elevations, the Blue Nile and the Atbara have their rise.

On the north, the basin is bounded by the Himalayas, and the lofty ranges which, under various names, continue to the west, and, without any important break, join on to the mountain districts of the Caucasus and of Asia Minor.

This chain of mountains, rivalled in length only by the Andes, unequalled in the whole world, whether in its mean height, the height of its principal peaks, or the area which it covers, forms one uninterrupted and very elevated line from the interior of China to the shores of the Black Sea. The stupendous height of the Himalayas is well known: north of them is the country of Thibet, as yet but little explored, but in which the mountains attain a height scarcely, if at all, inferior to that of the highest peaks of the southern chain. To the west is the giant range of Hindoo Koosh, amid the spurs and valleys of which lie the countries bearing the more familiar names of Afghanistan and Beloochistan. Still further west, the line of mountains passing south of the Caspian Sea, and turning northward, forms the wild country of the Caucasus and Armenia; and a spur, running due west, under the name of the Taurus, borders the southern coast of Asia Minor.

The very great elevation which this mountain range has throughout its entire length, dwarfs the smaller hills in its neighbourhood; and districts, which are not, strictly speaking, either level or low-lying, appear to be so when compared with the rugged highlands which shut them in. Central Arabia, for instance, is a more or less fertile plain, whose mean elevation above the sea may, in the absence of exact measurement, be estimated at about 3,000 feet:* but on all sides of this cultivated table-land is the wild, burning desert, where the red sand lies in undulating ridges, which can only be compared to the long, heavy swell of the wide ocean.† This is probably not more than a thousand feet above the sea; possibly not so much; and the hills on the south, which separate it from

* WILLIAM GIFFORD PALGRAVE: Central and Eastern Arabia, vol. i. pp. 91, 336.

† *Ibid.* i. 91.

the coast line and the Arabian Sea, do not, except in very isolated instances, reach a height greater than from two to three thousand feet.

In India, the northern part, when clear of the Himalayas, is almost a dead level. Lahore, the capital of the Punjaub, 500 miles from the nearest sea, is not 1,000 feet above it. The fall of the Ganges and Jumna, throughout by far the greatest part of their course is extremely slight; and Allahabad, at the junction of the two rivers, is less than 350 feet above the sea. South of this the land rises considerably; the Western Ghauts, on the Malabar coast, reach a height of from four to six thousand feet; on the Coromandel coast the mountains are not so high, and may rather be considered as the border of the elevated plains, which, under the name of the Deccan, stretch from the west across the whole southern part of the peninsula. In the south, where the Western and Eastern Ghauts approach each other, the elevated district between rises still higher, and, in the Nilgherry Hills, occasionally attains a height of nearly nine thousand feet.

The mountainous countries which form the eastern boundary of the basin have been by no means satisfactorily explored. We know that mountain ranges run, in a southerly and easterly direction, from the interior of Western China to the extremity of the Malay Peninsula, and form a central ridge in the Island of Sumatra; but very little is really known of their height or extent. Until within these last few years, it was commonly supposed that they were, at least, so continuous as to present a very rugged barrier in the way of all communication and transport; but it has recently been urged, on what appears to be good authority, that, up the valley of the Irawaddy the ascent is so gentle as to suggest the possibility of leading a railway direct into the western provinces of China, and of thus opening out their commerce to an extent

hitherto scarcely hoped for. The feasibility of such a scheme must be determined by more exact survey; but it would seem to be tolerably certain that, following the longitudinal valleys between the loftier ranges, there are lines on which the heights to be overcome are not very great, although the ranges themselves appear to be both rugged and continuous, and form a tolerably distinct boundary between the atmospheric currents on their east and west side.

Over the whole of the North Indian Ocean, including the Arabian Sea and the Bay of Bengal, the wind may be said, in general terms, to blow from the north-east in winter, and from the south-west in summer. The exact direction varies somewhat in different localities; but it lies, for the most part, between north and east in the one season, between south and west in the other. These winds, blowing with great constancy, and changing in their seasons, year after year, with undeviating regularity, are known as the NORTH-EAST and SOUTH-WEST MONSOONS: it was as given to them, that the name MONSOONS first became familiar to European navigators, in the sixteenth or early in the seventeenth century; and though it has since been applied, by some authors, to winds which change periodically in other parts of the world, it is to these winds of the Indian Ocean and China Seas only that it is with strict correctness applicable.

In the open sea the NORTH-EAST MONSOON blows pretty steadily from the N.E., beginning about the end of October, and continuing till towards the middle of April. On the Malabar coast, and on the eastern coast of the Bay of Bengal, however, the prevailing direction of the NORTH-EAST MONSOON during the greater part of this time is from the west of north, or nearly parallel to the coast line, whilst on the western sides of the two great bays—that is

to say, on the Coromandel coast and the coast of Africa, its mean direction is north, or N.N.E.; and on the Arabian coast, again, it is much more easterly, and blows with remarkable steadiness from about E.N.E.*

The SOUTH-WEST MONSOON sets in about the beginning of May, and lasts till towards the end of September. Its general direction over the greater part of the Arabian Sea is from between S.W. and W.S.W.; but on the Malabar coast, on the west coast of Ceylon, and to the southward, it prevails very commonly from west, or from the north of west. In the Bay of Bengal its direction is more southerly; and on the Coromandel coast it not unfrequently blows from even the eastward of south.

The distinguishing characteristic of the South-West Monsoon is its humidity. It is accompanied by heavy rain, which prevails more or less over the whole Indian Peninsula during the months of June, July, and August. The Malabar coast, where the wind strikes on the slopes of the Western Ghauts, is especially remarkable for the quantity of rain which falls at this season; and along the whole western coast, as far north as the mouths of the Indus, the rain-fall is very great. The coasts on the eastern side of the Bay of Bengal are also subjected to long-continued and heavy rains during the South-West Monsoon; and at the head of the bay, at Calcutta and the neighbourhood, the climate is almost insupportable, in consequence of the great quantity of moisture which the southerly wind brings with it: moisture which, carried over the low country by the continuous breeze, is thrown down in deluging showers on the mountains of Nepaul, Sikkim, Bhotan, or still further to the east, where, in Khasia, the rain-fall is the greatest yet known.

But besides the heavy rain which always accompanies it, the season of the South-West Monsoon has an evil

* HORSBURGH: i. 135.—Board of Trade Chart.

reputation amongst sailors as a season of bad weather. The wind is, for the most part, boisterous, unequal, and often interrupted by heavy and dangerous squalls, more especially in the Bay of Bengal. The neighbourhood of the Nicobar Islands, and the northern parts of the Straits of Malacca, are particularly subject to these. Violent squalls from the south-west, known as SUMATRAS, are the most common; but squalls from the north-west are also frequent.

As the season of the South-West Monsoon draws near its close, the weather becomes worse, and by the middle of September is fairly broken. There is then about a month or six weeks of unsettled and variable winds, during which very dangerous storms occur almost annually. Most of these are distinguished by the same peculiarities as the HURRICANES of the West Indies, or the TYPHOONS of the China Seas, especially by the continual change in the direction of the wind, and by the enormous volume of water which they raise up as a wave, carry along with them, and hurl with destructive force on the coasts against which they strike. The Bay of Bengal is more particularly subject to these dreadful storms; and scarcely an autumn passes without a record of some terrible disaster, whether to the shipping of all classes and countries which swarms in those waters, or to the villages and towns of the coast—from Calcutta to Pondicherry or Tranquebar—swept away by the storm-wave.

Of these, one of the most celebrated in the annals of our navy is that of the 20th October, 1782, when Sir Edward Hughes' fleet, lying before Madras, had barely time to put to sea and gain an offing. As it was, several of the ships were dismasted; and the storm-wave which broke on Madras destroyed a very large number of coasting vessels, and caused a most frightful famine, which carried off the inhabitants by thousands.

A similar period of unsettled weather occurs at the

commencement of the South-West Monsoon—that is to say, in April or May. Violent gales may then also be expected; but though they blow often with great fury in the Arabian Sea, and on the west coast of Hindostan, they are, like the autumnal gales, more common in the Bay of Bengal, and especially on the Coromandel coast.

Such a one was the well-known storm of the 13th April, 1748, when the "Namur" (74), Admiral Boscawen's flag-ship, and the "Pembroke" (60), with almost all hands, were lost near Pondicherry: only twelve men of the "Pembroke" and twenty-four of the "Namur" being saved, in addition to the admiral and some few officers, fortunately on shore at the time. The gale began on the night of the 12th at N.N.W., and continued all the next day. "Its greatest violence was between eight at night of the 13th, and two the next morning, shifting all round to the east till it came to the south, where it ended."*

But though these storms are extremely violent, and, from the continual shifting of the wind, dangerous, they are, nevertheless, seldom so destructive as the gales of autumn, neither are they so frequent; and the change from the North-East to the South-West Monsoon often takes place without any more marked occurrence than a few weeks of calms, interrupted by puffs from the east or west. But invariably, between the two monsoons, whether the change is in autumn or spring, from the South-West to the North-East, or contrariwise, from the North-East to the South-West, there is a period varying in length from one month to two, during which the wind is uncertain, the weather is unsettled, and violent storms may be expected. This period is known as THE BREAKING OF THE MONSOON.

In the Red Sea the wind changes its prevailing direction at about the same times of the year as the monsoons change in the Arabian Sea. During the North-East

* BEATSON: Nav. and Mil. Memoirs, vol. i. p. 401.

Monsoon, which on the southern coast of Arabia has more easting than in other parts of the sea, a southerly wind blows up the Red Sea. This, which in the southern parts is commonly a fresh breeze from the south-east, seldom reaches beyond Jiddah; and, though it does occasionally extend as far as Suez, more particularly in the months of December and January, calms and northerly winds are more common in the northern part of the sea, even at that season. During the prevalence of this southerly wind, especially from October to January, "in the lower part of the sea, the weather is generally thick and hazy, obscuring objects until pretty near; and along the outer reefs, squalls and rain are frequently experienced in November and December."*

Towards the end of the season of the North-East Monsoon, this southerly wind becomes very uncertain, being often interrupted by calms and northerly winds; and by the beginning of June a north-westerly wind takes its place, and blows with great steadiness down the whole length of the Red Sea, from Suez to Bab-el-Mandeb, till towards the end of September. This wind, however, is not, as a rule, so strong as the south-easterly wind of winter; and although it does occasionally blow with great violence, the northerly gales seldom last for more than a few hours.

Of the winds that prevail over the peninsula of Arabia, we have no certain information. The extraordinary ridges in which the sand of the desert everywhere lies—ridges which run with remarkable regularity in a northerly and southerly direction, would seem to be caused by a wind blowing very persistently from either west or east; but there is no positive evidence in support of this inference, so that it is impossible to speak with any certainty. On the other hand, the large round holes, which Mr. Palgrave

* Horsburgh: i. 369.

noticed, would lead us to infer the frequency of very violent whirlwinds. He describes these holes as "vast funnel-like depressions," "hollowed with an exactness of circular form truly surprising," and so deep as "to leave bare the chalky bottom-strata below." "Such cavities (he says) are not uncommon amidst the sands, and occur in a very arbitrary manner, independent it would seem of the general laws of the desert. Their great size secures them against filling up; the pit in which we passed the night could not have measured less than a quarter of a mile at its upper diameter, from rim to rim, and its depth was certainly about eight hundred feet. . . . I met with them alike in the Nefood and Dahna, in the northern and southern desert."*

I shall have occasion, further on, to speak more at length on the subject of whirlwinds; but the enormous lifting power which they commonly display is so well known, that I feel at liberty to allude to it here, as affording what appears to be a probable explanation of the origin of these very singular pits.

But the Arabian wind, of which we have the most exact accounts, and which, from the peculiar disasters which have often resulted from it, has obtained a terrible celebrity, is the hot blast from the desert, which in different localities and by different tribes of Arabs is called the *shelook* (a name changed in the Lingua Franca and Italian into *scirocco*), *simoom*, or *samiel*. This wind, occasional indeed, but by no means uncommon in regions bordering on the desert, whether of Arabia or Africa, seems to blow, for the most part, towards the north. Comparatively unknown in the countries or seas to the southward of the deserts of the northern hemisphere, it is a frequent scourge in the northern parts of Arabia, in Egypt, Algeria, and Morocco. Mr. Palgrave's life-like account of

* PALGRAVE: *Op. cit.* i. 99.

a short squall of this nature, which he experienced in the neighbourhood of Wadi Sirhan,* will perhaps give a better idea of its character than a more general description. He says:—"It was about noon, and such a noon as a summer solstice can offer in the unclouded Arabian sky over a scorched desert, when abrupt and burning gusts of wind began to blow by fits from the south, while the oppressiveness of the air increased every moment, till my companion and myself mutually asked each other what this could mean and what was to be its result. We turned to inquire of our guide, but he had already wrapped up his face in his mantle, and, bowed down and crouching on the neck of his camel, replied not a word. His comrades had adopted a similar position and were equally silent. At last, after repeated interrogations, the guide, instead of replying directly to our questioning, pointed to a small black tent, providentially at no great distance in front, and said—'Try to reach that. If we can get there we are saved.' He added—'Take care your camels do not stop and lie down; and then, giving his own several vigorous blows, relapsed into muffled silence. . . .

"The gusts grew hotter and more violent, and it was only by repeated efforts that we could urge our beasts forward. The horizon rapidly darkened to a deep violet hue, and seemed to draw in like a curtain on every side; while at the same time a stifling blast, as though from some enormous oven opening right on our path, blew steadily under the gloom. Our camels, too, began, in spite of all we could do, to turn round and round, and bend their knees, preparing to lie down. The semoom was fairly upon us. . . . So dark was the atmosphere, and so burning the heat, that it seemed that hell had risen from the earth, or descended from above. But we were yet in time, and at the moment when the worst of

* Latitude, 30° N.; longitude, 38° E.; approximately.

the concentrated poison-blast was coming around, we were already prostrate, one and all, within the tent, with our heads well wrapped up, almost suffocated, indeed, but safe; while our camels lay without like dead, their long necks stretched out on the sand, awaiting the passing of the gale. . . .

"We remained thus for about ten minutes, during which a still heat, like that of red-hot iron slowly passing over us, was alone to be felt. Then the tent walls began again to flap in the returning gusts, and announced that the worst of the semoom had gone by. We got up, half dead with exhaustion, and unmuffled our faces. My comrades appeared more like corpses than living men, and so, I suppose, did I. However, I could not forbear, in spite of warnings, to step out and look at the camels; they were still lying flat, as though they had been shot. The air was yet darkish, but before long it brightened up to its usual dazzling clearness. During the whole time that the semoom lasted, the atmosphere was entirely free from sand or dust; so that I hardly know how to account for its singular obscurity."*

A resident in Algiers, on the contrary, describes the air during a scirocco as "full of a dust so thick and fine that one mistook it for a fog—the clouds of flying sand eclipsed the obscured disk of the sun, and the different shades of yellow, orange, saffron, and lemon colour melted into a mass of copperish colour impossible to describe."† Many others also, in other places, have spoken as decidedly of the clouds of dust borne along by similar winds; and it appears certain that they are frequent, if not constant, attendants on the scirocco or simoom.

Over the peninsula of Hindostan the winds partake very much of the nature of the monsoons which prevail

* PALGRAVE: *Op. cit.* i. 17.

† M. B. EDWARDS: A Winter with the Swallows, p. 253.

at sea. During the winter they blow mostly from the north and north-west, are dry, and for the most part pleasant and cool; but towards the end of the season they become exceedingly hot, and are accompanied, more especially in the north-western provinces, by clouds of dust and sand, the burning heat of which, as it is carried along in the air, most disagreeably augments the temperature.* Near the deserts of the Punjaub, in the months of March, April, and May, sand storms are of common occurrence, which are frequently of the nature of whirlwinds; and in the neighbourhood of Lahore several enormous columns of sand may often be seen whirling about, and travelling each on its independent path, or waltzing round each other in what appears the most confused and capricious manner.† But far to the southward of that sandy district a dust haze pervades the atmosphere whilst the north-west wind is blowing, and, together with an excessive dryness, is its distinguishing characteristic.‡

The latter part of the northerly monsoon, and until the wet monsoon of summer is fairly established, is, throughout India, familiarly spoken of as the "hot season," a name appropriately given to it on account of the extreme heat which then prevails—a heat due not only to the direct influence of the sun, approaching the northern tropic, and shining through an unclouded sky, but also, and in an especial degree, to the continuous northerly wind, superheated in its passage over the burning deserts of the Punjaub and the north-west frontier. But the westerly monsoon, with its heavy rains, brings in a season scarcely more endurable. Although the temperature is then markedly diminished, the extreme humidity of the air manifests itself in an all-

* Dr. H. DE SCHLAGENTWEIT: On the Numerical Elements of Indian Meteorology; in Philosophical Transactions, 1863, p. 541.

† P. F. H. BADDELEY: Whirlwinds and Dust Storms of India, p. 5.

‡ Dr. J. D. HOOKER: Himalayan Journals, vol. i. pp. 15, 21, 58.

pervading dampness, which makes everything feel moist and clammy, and which, checking the perspiration, entirely does away with the sensible relief that would be given by its evaporation.

The rains, in general, commence early in June, though the exact time varies in different districts, and even in the same place has a range of several weeks. At Simla the wet season usually begins about the 20th June,* or between that date and the end of the month. Further south, in the low country, it is, as a rule, somewhat earlier. In 1857, it was noted that the rains in the valley of the Ganges were much later than usual—a circumstance specially mentioned by the historian of the tragic siege of Cawnpore, as permitting the longer defence of the slender fortifications, which in the tropical rain would have been uninhabitable. The rains did not begin till the day after the surrender of the encampment to the treacherous Nana; and in consequence of the long drought, the Ganges was so low that the boats, in which the scanty remnant of the defenders attempted to escape, grounded on the shoals and sand banks. This was on the 27th of June.†

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## SECTION VII.

### The Basin of the South Indian Ocean.

The Basin of the South Indian Ocean is bounded on the west by the highlands of Eastern Africa, and extends on the east to the coast of Australia. It is impossible, with our present scanty knowledge of the interior of that island, to fix the eastern boundary with any accuracy. It may, and probably does, lie as far to the east as the known

* Dr. Thomas Thomson: Western Himalaya and Tibet, p. 21.

† G. O. Trevelyan: Cawnpore, pp. 219, 237, 259.

mountain range already spoken of as the western limit of the Basin of the South Pacific; but far to the west of this there may be mountain districts yet undiscovered, which shut in the low-lying country of the interior.

It is most commonly supposed that there are no such districts of any very great extent, and it seems scarcely possible that there can be, after the many exploring expeditions which have so laboriously threaded their way in different directions. The entire absence of rivers on the western side of the island may also be considered as affording very strong evidence that there is no mountain range near that coast; for it is difficult to conceive that there could be such a range in a country subject to heavy rains, without its pouring into the sea during the wet season great volumes of water, as is done by the mountains of the east coast, whether by the streams that flow eastward, or by the Murray and its numerous tributaries on the west. And in the absence of such torrents on the west coast, we may conclude that the land, having no effective drainage to the sea, allows the water to lie on the surface until it soaks into the sandy soil, or is evaporated by the desert heat. I, therefore, though with no absolute certainty derived from positive testimony, would place the eastern boundary of this basin to the eastward of the deserts of Central Australia, in the mountain ranges of the east, the Australian Alps, the Blue Mountains, and their continuance northward under many local names.

On the west, the mountains of Eastern Africa rise almost immediately from the coast. The lowland does not, as a rule, extend further than a hundred miles inland, from which point the country slopes upward, or rises in a wild and picturesque manner to the height of from four to six thousand feet, and we are thus, as far as our present inquiry is concerned, limited to the sea by an almost unknown mountain district on one side, by a country still

more unknown, but believed to be, for the most part, a flat, low-lying desert, broken by hills of considerable altitude, on the other.

During the winter months a south-easterly wind blows very constantly in the South Indian Ocean, from about the parallel of 25° S. to the equator. This wind is known as the SOUTH-EAST TRADE, and is throughout the winter steady and of moderate strength, its general direction being from about S.E. as far north as the parallel of 12° S., where, in mid-ocean, its easting becomes much more marked, and, near the equator, it blows frequently, though with no great force, from almost due east. Near the coast of Australia, on the other hand, south of the North-West Cape, its direction is more southerly; but on the north-west coast, and between that and the islands to the northward, as well as amongst the islands, the wind prevails at that season from E.S.E. or east, with a strength that occasionally amounts to that of a fresh gale.

During the summer months the Trade does not blow to the north of 10° or 12° S. From that, northward to the Line, a north-westerly or westerly wind, veering often to the south-west, prevails across the whole breadth of the ocean, and blows fresh from about W.S.W. into the narrow sea between Australia and Java, and from nearly due west through Torres Straits. *

This change from an easterly wind in winter to a westerly wind in summer, in the zone extending from the parallel of 12° to the Line, is very clearly marked, the winds from these almost opposite directions occurring each season with undeviating regularity; they are, there-

* Wind Charts of the Royal Dutch Meteorological Institution, 1856. —HORSBURGH: i. 138, 168.—KING: Survey, etc. ii. 323.—RATTRAY: in Journ. of Roy. Geog. Soc. vol. xxxviii. p. 384.—A. R. WALLACE: The Malay Archipelago, vol. ii. pp. 331, *et seq.*; 370, *et seq.*

fore, called the EASTERLY and WESTERLY MONSOONS, or frequently, with an apparent pretence of greater exactness, the SOUTH-EAST and NORTH-WEST MONSOONS. But in reality, the SOUTH-EAST MONSOON blows very commonly from east, and not unfrequently from E.N.E.; as, on the other hand, the NORTH-WEST MONSOON is often met with blowing from west and W.S.W.

On the western side of the ocean, to the eastward of the Island of Madagascar, the North-West Monsoon frequently stretches far to the southward; and in the middle of summer prevails near the Mauritius, and even still further south. In this part of the sea its direction is northerly, and though mostly from about N.N.W., it often blows from north, and even from N.N.E. So far to the southward, however, it does not blow with the same constancy as in lower latitudes, and is frequently interrupted by breezes from the south-east, which drive away the moisture of the northerly wind, and usher in pleasant, cool weather, even in the middle of the hot season. But the North-West Monsoon is everywhere accompanied by damp, sultry weather and heavy rains; and at the Mauritius, as well as on the north-west coast of Australia, in Java, and the innumerable islands to the eastward, the North-West Monsoon is a season of rain, such as is known only within, or in the vicinity of, the tropics.

The alternating monsoons prevail also in the northern part of the Mozambique Channel, though their direction is there decidedly different from what it is in the open sea, the monsoon of summer blowing from the north-east, and that of winter from the south-west; but in the southern part of the channel, winds from between S.W. and S.E. prevail all the year round. Near the south end of Madagascar the easterly wind is very constant, and blows past Fort Dauphin in occasional fresh breezes known as *Fort*

*Dauphin Winds*, which commonly reach home to the African coast. *

During the months of summer, that is, whilst the North-West Monsoon is blowing, there is between it and the South-East Trade a narrow zone of uncertain and unsettled weather. In this, storms of the greatest known violence occur almost every year, and very few seasons indeed pass without, at least, one. In consequence of the continual traffic over this sea, crossed as it is by all ships bound to any part of India or China, these storms have been laid down on the charts with great exactness, and it is thus shown that they almost invariably commence well to the eastward, sometimes even not far from the meridian of Java Head, and travel to the westward at a rate which varies from two hundred to fifty miles in the twenty-four hours. They present all the peculiarities of the West Indian storms, already spoken of as Hurricanes, and from the French, long the holders of the Mauritius, have received the same name, HURRICANES; but, for reasons that will be explained further on, when I examine more at length into the nature and distinguishing features of this remarkable class of storms, they are now more commonly designated CYCLONES. The difference, however, is one of name merely. They seem to be, to all intents and purposes, hurricanes in a different locality. The wind has the same extraordinary force, and continually changes its direction in a similar manner. There is a similar display of violent electric action, and though the storm-wave is seldom so marked, still, as, with the exception of the small islands, Rodriguez, Réunion, or Mauritius, there is no land in its track on which it can burst, it may easily be conceived that the absence of a coast line prevents its producing the usual and destructive effects—effects, indeed, which are much more disastrous on a continuous coast,

* HORSBURGH: i. 233.

the Coromandel Coast, for instance, than even amongst the islands of the West Indies. These storms scarcely ever occur except during the summer, or season of the North-West Monsoon, and for the most part towards the end of that season, in February and March. Mr. Thom says: "The season in which hurricanes occur in the Indian Ocean, south of the equator, is generally considered to extend from December to April, or hottest months in that hemisphere. Those with which we are acquainted have taken place in the following order:—

| | | |
|---|---|---|
| November | 1. | On the 21st. |
| December | 3. | |
| January | 10. | |
| February | 16. | |
| March | 17. | |
| April | 10. | |
| May | 1. | On the 3rd. |

During the rest of the year tempests are unknown. The Trade wind occasionally prevails, in the winter months, to the extent of what may be called a fresh gale, but can neither be compared to the terrific force of the hurricane, nor is it marked by much change in its direction." *

The Trade wind does, however, within certain limits, veer through several points; and, especially in winter, when it is, as a rule, stronger than in summer, is often fixed for several days at east or E.N.E.† In summer, on the other hand, it extends further to the south, prevailing very decidedly as far as the parallel of 30° S., and frequently reaching, as a fresh easterly gale, to the Cape of Good Hope.

* ALEXANDER THOM, Surgeon, 86th Regt.: An Inquiry into the Nature and Course of Storms in the Indian Ocean, South of the Equator, 1845, p. 136.

† HORSBURGH: i. 168.

On the west coast of Australia, from Cape Leeuwin, the south-western extremity, to the North-West Cape, "the winds blow for the most part from some southern point, chiefly between S.S.W. and S.S.E. During summer, from the early part of October to the beginning of April, they are almost constant from this quarter: in winter their regularity is broken in upon by occasional winds between west and north, that blow with great violence, and are accompanied by heavy rain and thick dirty weather."*

The prevalence of south-easterly winds in Central Australia is, judging from the description of the various exploring parties, very marked. According to Mr. Stuart, who conducted several expeditions on a line nearly due north from Adelaide, and at last succeeded in reaching the northern coast, any other wind is quite exceptional. On every day throughout June, 1862, in or near latitude 15° S., he notes a wind from between south and S.E., and observations in other months, and in different journeys, show no trace of any considerable alteration.† Further south, the wind draws round to the west of south, and, in some seasons, at least, blows up the valley of the Murray River with great force and regularity.‡

South of the parallel of 40° S. strong westerly winds prevail all the year round: these extend far to the south, and have already been spoken of as winds which in the Great Southern Ocean completely encircle the world; but between them and the Trade there is, in the southern part of the South Indian Ocean, a well-marked district where

* Horsburgh: i. 138.—King: ii. 366.—J. Lort Stokes, Commander, R.N.: Discoveries in Australia, vol. ii. p. 153; and in App. by Commander J. C. Wickham, vol. ii. p. 531.

† John M'Douall Stuart: Journals, etc., during the years 1858—1862. Edited by William Hardman, *passim*.

‡ Captain Charles Sturt, 39th Regt.: Two Expeditions into the Interior of South Australia, 1828—1831, vol. ii. p. 153.

the winds are unsettled and the weather broken. This district does not extend to the coast of Australia on the east, where fresh southerly winds predominate at all seasons; and though it occasionally is found to reach the African shores on the west, it is for the most part confined to the open sea, at some distance from the land on either side. It changes its position with the seasons; and, according as the southern limit of the Trade approaches to, or recedes from, the equator, the latitude of this region of unsettled weather diminishes or increases. At the Island of St. Paul, nearly midway between the Australian and African coasts, the heavy westerly wind of the Southern Ocean blows throughout the winter; but in the summer months, the island is in the district of variable winds, those from the south predominating. The winter is thus a season of foul weather, rain and constant gales from between N.W. and S.W.; and the summer, from November to April, is fine and pleasant, the wind being southerly and the sky clear often for weeks together. In November, 1857, some officers of the Austrian frigate, "Novara"—landed there to complete an accurate survey of the island—experienced, what was said to be, exceptionally bad weather; north-westerly gales, accompanied by heavy rain, blowing frequently during their stay. But they also found the wind very commonly veering steadily round the compass, going from N.E. to N.W., to S.W., and, through south, to N.E. again, a circuit which it performed several times in about six days, and always in the same direction.*

* Voyage of the "Novara:" vol. i. p. 293.

## SECTION VIII.

### The Upper Currents of the Atmosphere.

Wherever observations have been made of the upper currents of the atmosphere—that is, of the winds at a considerable height above the surface of the earth—it has been found that, with very few exceptions, they blow with remarkable uniformity from the west. These observations are necessarily limited in number and isolated in position, as compared with those which have been made of the winds of the lower atmosphere, the directions of which are, in all places, subjects of every day experience, and of general interest; whilst the direction of the upper current is not likely to be noticed except by regular observers, or where it is specially remarkable by its contrast with that of the lower winds.*

It is in this way that many instances have been recorded of the upper clouds, in the region of the Trade winds, flying towards the east, whilst the Trade wind was blowing fresh below. In the North Atlantic this drift has been repeatedly mentioned as from the south-west. In the South Pacific, between the Equator and the parallel of 18° S., Captain Wilkes, of the United States Navy, noticed it, in August, as being commonly from the south-west.† On Mauna Loa, in Hawaii, where his party remained for twenty days, he experienced, at a height of 13,760 feet, a succession of south-westerly winds, which he describes as

* Remarks on Mr. Green's Balloon Ascents, in the Ninth Number of the Meteorological Papers, published by authority of the Board of Trade, 1861, pp. 26, *et seq.*

† U.S. Expl. Exped., i. 310.

"violent gales" or "perfect hurricanes." On one occasion, he says:—"The wind had been fresh throughout the day, but towards night it began to increase, and by eight o'clock we had another violent gale from the south-west. It blew a perfect hurricane for several hours. . . . The two other tents were blown down, but mine stood firm."*. And in going up, he notes that, "instead of Trade winds from the north-east, we had a mountain breeze from the west, which caused the temperature to fall to 43°, and produced a feeling of great cold, being a fall of 40° since we left the coast."†

Count Strzelecki also, ascending the same mountain, found, "within the elevation of 6,000 feet, three currents of different directions, intensity, and thermometrical condition. That of Hilo (Byron's Bay) was a very light S.E. current, with a temperature of 86°; that at an elevation of 6,000 feet was a brisk N.W. wind, temperature 67°; while, as an intermediate between these, at an elevation of 4,000 feet, a strong westerly wind moved in the temperature of 55°."‡

A very strong westerly gale has been noted by many travellers as experienced in crossing the Andes, from the Pampas to Valparaiso; § and from the reports of their guides, they speak of such a wind as being the rule in these elevated regions: but further north, even at very great elevations, it has not been observed as at all prevalent. Humboldt speaks of the "icy winds of the South" as making a journey over the Paramo del Assuay, in latitude 3° S., at a height of about 15,000 feet, "for-

* U.S. Expl. Exped. iv. 146. † *Ibid.* iv. 132.

‡ Physical Description of New South Wales, p. 163.

§ Lieut. CHARLES BRAND, R.N.: Journal of a Voyage to Peru, etc. 1828, chap. v. See also Dr. GILLIES, in Edinburgh Journ. of Nat. and Geograph. Science, 1830, p. 317.

midable;"* and Ulloa's experience seems to have been almost identical.† Dr. Hooker also in the Eastern Himalaya, at a great height, found southerly winds prevailing, even during the period of the northerly monsoon. He says:—"The southerly or sea wind blows steadily from May till October in Sikkim, and prevails throughout the rest of the year, if not as the monsoon properly so called, as a current from the moist atmosphere above the Gangetic Delta. This rushes north to the rarified regions of Sikkim, up the great valleys, and does not appear materially disturbed by the north-west wind which blows during the afternoons of the winter months over the plains, and along the flanks of the outer range." . . . "Though the direction of the main atmospheric current is to the north, it is in reality seldom felt to be so, except the observer be on the very exposed mountain tops, or watch the motions of the upper strata of atmosphere. Lower currents of air rush up both the main and lateral valleys throughout the day; and from the sinuosities in the beds of the rivers, and the generally transverse direction of their feeders, the current often becomes an east or west one."‡

On the other hand, the westerly upper current predominates in a very marked manner over the whole of North America, or at least over the whole of the United States. Mr. Blodget says that, in the western part of the State of New York, in three years, during which he carefully observed the direction of the upper current, he did not detect more than three instances of its moving in an opposite direction, and these were during violent surface storms; that though of course the higher strata of clouds were frequently obscured by the lower, there were still very few days in which a break did not occur sufficient to permit an attentive observer to see the direction of their motion, and that this was uniformly from the west, not-

* Researches, etc., i. 240. † Pinkerton's Collection, xiv. 431.
‡ Himalayan Journals, ii. 389, 393.

withstanding easterly gales which might be blowing lower down.* This statement is supported by the weight of the official observations, which show a singular preponderance of westerly winds at a distance above the surface of the earth, a preponderance which is not less than three-fourths of all the upper currents observed. At South Pass, in the Wind River Mountains, the west wind is said to be almost invariable; and on the elevated ridges it has a uniform violence which in a curious and noticeable manner modifies the shape of the weather-beaten rocks.†

In the North Atlantic, the eastward drift of the clouds has been constantly noticed by voyagers from very early times; and the distance to which ashes, shot into the upper air during volcanic eruptions, have been carried to the eastward, is a remarkable proof of the strength which this wind occasionally has. Some extreme instances of this are worthy of more particular mention.

"In the night of the 30th of April and 1st of May, 1812, explosions, as if of heavy ordnance, were heard at Barbadoes, so that the garrison of Fort St. Anne was kept under arms. At break of day on the 1st of May, the eastern part of the horizon was clear, while the remainder of the sky was enveloped in a black cloud. The darkness soon extended over the whole sky to such a degree that the place of the windows could not be seen in the apartments, while the trees gave way under the load of ashes which fell on them. Where did these ashes come from? In the months of April and May the Trade wind is at its height, so that it would have been natural to conclude that they had come from the volcanoes of the Azores. The true source of the ashes was the volcano of Morne Garou, on the island of St. Vincent, which lies 100 miles west from Barbadoes, and from which it is impos-

* Climatology of the United States, p. 358.

† Capt. R. F. Burton: The City of the Saints, p. 202.

sible to reach Barbadoes by sea, without taking a very circuitous route, in consequence of the direction in which the Trade wind blows. The ashes from the volcano had been thrown by the violence of the eruption through the under Trade wind into the upper counter-current. Again, on the 20th of January, 1835, the whole isthmus of Central America was shaken by an earthquake, which accompanied the eruption of the volcano of Coseguina on the Lake of Nicaragua. The violence of the eruption was enormous, so that the sounds were heard at Santa Fé de Bogotá, at a distance of 1,000 miles; while the cloud of ashes was so dense that Union, a sea-port town on the west coast of the Bay of Conchagua, was enveloped in total darkness for forty-three hours. Ashes fell also at Kingston, and at other places in Jamaica, so that the inhabitants were able to learn that the explosions which they had heard had not been those of cannon. These ashes could not have been carried to Jamaica except by the counter-trade wind, as that island lies to the north-east of Nicaragua." *

In another part of the world a still more remarkable instance is noted by Sir Charles Lyell:—"In April, 1815, one of the most frightful eruptions recorded in history occurred in the province of Tomboro, in the island of Sumbawa, about 200 miles from the eastern extremity of Java. In April of the preceding year the volcano had been observed in a state of considerable activity, ashes having fallen upon the decks of vessels which sailed past the coast. The eruption of 1815 began on April 5th, but was most violent on the 11th and 12th, and did not entirely cease till July. The sound of the explosion was heard in Sumatra at the distance of 970 geographical miles in a direct line; and at Ternate, in an opposite

* H. W. DOVE: Law of Storms, trans. by R. H. Scott, p. 37. (I have throughout referred to this translation as being authorized by Prof. Dove, and more accessible to the general reader.)

direction, at the distance of 720 miles. Out of a population of 12,000 in the province of Tomboro, only twenty-six individuals survived. Violent whirlwinds carried off men, horses, cattle, and whatever else came within their influence, into the air; tore up the largest trees by the roots, and covered the whole sea with floating timber. Great tracts of land were covered by lava, several streams of which, issuing from the crater of the Tomboro Mountain, reached the sea. So heavy was the fall of ashes, that they broke into the resident's house at Bima, forty miles east of the volcano, and rendered it, as well as many other dwellings in the town, uninhabitable. On the side of Java the ashes were carried to the distance of 300 miles, and 217 towards Celebes, in sufficient quantity to darken the air. The floating cinders to the westward of Sumbawa formed, on April 12th, a mass two feet thick and several miles in extent, through which ships with difficulty forced tlieir way.

"The darkness occasioned in the daytime by the ashes in Java was so profound that nothing equal to it was ever witnessed in the darkest night. Although this volcanic dust when it fell was an impalpable powder, it was of considerable weight when compressed, a pint of it weighing twelve ounces and three-quarters. Some of the finest particles were transported to the islands of Amboyna and Banda, which last is about 800 miles east from the side of the volcano, although the south-east monsoon was then at its height. They must have been projected, therefore, into the upper regions of the atmosphere, where a counter-current prevailed." *

I have given these extracts at length, because they set forward, in the most striking manner, the very exceptional nature of the circumstances under which this evidence of a strong upper current from west to east has been obtained.

* Principles of Geology, Tenth Edit. vol. ii. p. 105.

Such instances are, fortunately for the peace of the world, extremely rare; and whilst the fact that, in these, large quantities of ashes were thus borne to the eastward, may not be admitted as a decisive and absolute proof of the constancy of the westerly wind, in the upper regions of the atmosphere, in those parts of the world, the consideration that the extraordinary events, which bear witness to its occasional existence, occurred at irregular and apparently accidental intervals, gives a high degree of probability to the belief in such a constancy, and is strongly corroborative of the evidence more commonly furnished by the drift of the clouds.

Evidence more persistent, and altogether to the same effect, is given by numerous observations on the Peak of Teneriffe. For many years travellers have been in the habit of reporting that on the top of the peak they found a strong south-west wind, whilst the north-east Trade was blowing at the foot of the mountain. Baron Humboldt and Captain Basil Hall are two whose names readily recur to me as having many years ago mentioned this striking phenomenon; but they are only two out of a host who have left the same testimony. We have lately been able to add to these a testimony still more satisfactory, as being the testimony of a skilled observer not pressed for time. It is that of Professor Piazzi Smyth, who, a few years since, in a fit of astronomical enthusiasm, spent two months at very elevated stations on the peak. As the result of his experience, he expresses a firm belief in the permanency of a south-westerly upper current; and though he is so thoroughly persuaded of its existence, that he continually speaks of it as passing overhead even when the manifestations of it may be considered doubtful, still, a careful study of his interesting little book* will lead to the conviction that a westerly or south-westerly wind did blow

* C. PIAZZI SMYTH: Teneriffe, an Astronomer's Experiment, 1858.

frequently, if not constantly, at a greater or less height; and as his descriptions bear so directly on the subject under consideration, I need offer no apology for laying some of them before the readers of these pages.

On the 18th of July the party experienced a stiffish gale from the south-west. After speaking of its effects on the encampment, he goes on:—"With evening the wind died away. Then appeared the unusual summer sight, for Guajara of clouds—that is, clouds on the sky above us, for there were the ordinary lower clouds over sea and land as a matter of course. Long we gazed at the novel upper clouds sailing over our heads from the south-west. . . . These upper clouds sailed clear over the peak, whose height is 12,200 feet, and were probably not less than 15,000 feet in elevation." * A few days later he experienced a severe gale from the north-east, the velocity of the wind in which he estimated as varying from ten to thirty miles an hour. "During all the period of greatest violence the usual sea of north-east cloud was at its ordinary elevation of only from 3,000 to 5,000 feet, and there were no upper clouds, yet here was the north-east current of wind felt, and in such intensity, at an elevation of 8,900 feet, and how much higher there was no saying." "The affair of this morning most eminently confirmed the general result of previous days, namely, that the north-east cloud is found low down in the north-east stratum of wind, and not, according to the general belief, midway between the north-east and south-west currents. That midway position appeared, from a summing of all our experiences, to be, in the summer-time, at least, of these latitudes, a region of calm as to wind, and of freedom from any sort of cloud. As the depth of the lower north-east current rose or fell, so did this zone of calm, which was only arrived at gradually by the air in motion above and below. The line of separa-

* C. PIAZZI SMYTH: Teneriffe, an Astronomer's Experiment, 1858, p. 113.

tion, therefore, must have fallen greatly, perhaps 3,000 feet, on the morning when we had the south-west storm; and now, with a similar visitation from the north-east, there must have been an equivalent rise. Hence we may at once see the futility of certain proposals to determine, by one or two ascents, the exact height of separation between the polar and equatorial currents, in a given latitude. If a few days had produced variations of several thousand feet, a few months, with their effects of season, would bring about far more change; and so, indeed, we found before we had finished with our expedition." *

Having moved his station to Alta Vista, 10,700 feet above the level of the sea, and on the slope leading to the peak itself, on the 25th August he went down to Orotava on business, and leaving the station with a south-west breeze, changed it, at an altitude of 6,700 feet, for one from the north-east. Returning again on the 30th, he experienced a similar change at about the same height, the strength of the wind increasing as he ascended. Arrived at the station, the south-west wind was found to be blowing with great violence, and it continued so to blow for rather more than a fortnight; when, as the

* A current of air, that is, a wind which blows from the direction of either pole towards the equator is called a *polar current*, and a wind, which blows from the direction of the equator towards either pole, is called an *equatorial current*. Thus, in the northern hemisphere, a wind that has any northing in its direction is a *polar wind*, and one that has any southing is an *equatorial wind*. In the southern hemisphere, of course, the names are exactly opposite. Such a nomenclature refers distinctly to the theory of Hadley, explained on a subsequent page, which maintains that the principal winds do actually come from the immediate neighbourhood of the poles or of the equator; but notwithstanding its frequent convenience, it seems to me objectionable, not only as embodying a theory, but also as implying that all winds have such a remote origin; whereas it cannot be doubted that at least very many are entirely local, and do not extend more than two or three hundred miles.

winter seemed to have set in, the party quitted the mountain.

Captain Burton has described a similar westerly or south-westerly wind, as blowing strong, and tearing the clouds to pieces far above the top of the Camaroons mountains, where, at a height of 13,000 feet, his party experienced, in January, an almost continuous easterly or north-easterly gale.*

The evidence, then, which tends to prove the existence of an upper current from the west may be stated briefly to be:—

1st. The observations of many voyagers, who, in different parts of the world, and particularly in the Trade wind regions of the Atlantic and Pacific Oceans, have reported that the upper clouds moved steadily towards the north-east.

2nd. The observations of many competent observers at many stations in the United States, which, as reported in official publications, show a number of westerly upper winds at least three times as great as the number of winds from other directions.

3rd. The well-authenticated fact that ashes shot up by volcanoes have been transported several hundreds of miles towards the east, even when a fresh easterly breeze was blowing near the surface of the earth.

Lastly. The actual experience, by numerous travellers and scientific observers, of a strong westerly wind, at very considerable elevations, not only in balloons in our own latitudes, but also on the passes of the Chilian Andes and of the Rocky Mountains, on Mauna Loa, on the Peak of Teneriffe, and on the Camaroons, in the immediate neighbourhood of the equator; and that very frequently when an easterly wind was blowing lower down.

* R. F. Burton: Abeokuta and the Camaroons Mountains, vol. ii. p. 165 and *passim*.

The cumulative nature of this evidence, collected from so many different parts of the world, in the absence of any conflicting testimony, permits us to consider it as establishing presumptively the fact that a westerly upper current does everywhere prevail, and that it frequently, if not most commonly, blows with a force equal to that of a strong gale.

# CHAPTER II.

## THE THEORETICAL CIRCULATION OF THE ATMOSPHERE.

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### SECTION I.

#### Recapitulation.

In the preceding pages I have endeavoured to lay before the reader a plain and accurate statement of well-ascertained facts. Basing my description of the winds which prevail in different parts of the earth, at different seasons, entirely on evidence, I have carefully refrained from all theoretical considerations, in order that we might have, in the first place, a clear account of the anemological phenomena which have been actually observed.

It is, however, impossible to study these phenomena without inquiring into their cause, without examining into the reason why certain winds should blow, with a greater or less constancy, in preference to others; why, for instance, within the tropics, we should so commonly find a steady easterly wind; or why, in high southern latitudes, we should find an almost continuous westerly gale.

The investigation of such problems involves questions of the highest interest, the solution of which, as it gradually enables us to seize in one comprehensive grasp the details of thousands of observations, may lead us by little and little to a correct and intelligent appreciation of the workings of those natural forces by which this world is

governed, may bring us nearer and nearer to that knowledge by which mind triumphs over matter, and which has already, in other branches of science, so far extended the dominion of civilized man.

The account already given of the winds of different countries and localities may be considered as propounding, in general terms, the problem of atmospheric circulation. A more concise summary will do so with greater exactness, and will permit me to point out the remarkable analogies, resemblances, or contrasts, which exist between them.

In each of the large oceanic basins—in the North and South Atlantic, in the North and South Pacific, and in the South Indian Ocean—there is between the tropics a constant wind blowing, in the northern hemisphere, for the most part from between north and east; and in the southern hemisphere, from between south and east, which in all these oceans is called the TRADE WIND. Contrary to what might have been expected, contrary to what, indeed, is very commonly asserted, the TRADE does not blow in the Pacific with either the strength or constancy that it has in the Atlantic or in the South Indian Ocean; and in the southern, or most open, part of the Pacific, it is frequently interrupted by westerly winds, which, to the west of the meridian of 130° W., and between the equator and the parallel of 18° or 20° S., prevail through the whole of the summer, and occasionally through the greater part of the year.

On the eastern side of each ocean the Trade wind extends further from the Line, and blows more directly towards it, more directly from the pole of its own hemisphere, than it does in any other part of the basin. On the north-west coast of Africa and the coast of Portugal, as well as on the coast of California, the Trade reaches far to the northward, the extension of it being often met with

as far north as 40° or 45° N., and blowing in that higher latitude from N.N.E., N., N.N.W., or even from N.W.; whilst on the west coast of Southern Africa, Australia, or South America, it blows most commonly from between S.S.E. and S.S.W.; and prevails, more especially in summer, as far south as the Cape of Good Hope, Cape Leeuwin, or the southern extremity of Chili.

Towards the western part of each ocean the Trade wind becomes more easterly: in the North Atlantic it blows amongst the West India Islands from east; in the South Atlantic it very commonly reaches the coast of Brazil also from the east; in the Pacific it blows along or parallel to the equator, both to the northward and southward of it, through many degrees of longitude; in the South Indian Ocean it prevails from due east, often for days together; and in all these different localities the direction, whilst approaching closely to east as a mean, is often from one side or the other of that point—frequently from E.N.E., frequently from E.S.E.

In North Africa—which may be considered as, to a certain extent, a basin of itself, secondary to the Basin of the North Atlantic—the winds appear to follow the same rule. On the eastern side, in Egypt and Nubia, they blow with very great constancy from the north; whereas, in the desert, all our observations, limited indeed in number, show that the prevailing direction of the wind is from the east. This easterly wind, too, is very frequently felt at sea, blowing hot from the coast of Africa, but the greater force of the Atlantic Trade would seem most commonly to carry it with it to the southward.

In the extreme east of both the Atlantic and Pacific Oceans, near the equator, there is a wide district where the winds are uncertain and the weather detestable. In both Oceans, a branch of the Trade wind from both hemispheres follows the direction of the coast line, or very

nearly so, and gradually dies out in a region where squalls, puffs from various quarters, mostly from the westward, heavy rain, violent thunderstorms, are almost the only interruptions to the stifling, humid calm that is most commonly experienced. And in both Oceans this region stretches out to the westward in a triangular form, its base resting on the coast, like a wedge thrust in between the Trades of the northern and southern hemispheres.

And of the Trades themselves it is to be especially noticed that they blow, more particularly in the Atlantic and South Indian Ocean, with a constancy, regularity, and pleasant, genial steadiness, of which no one acquainted only with the uncertain, variable, and frequently boisterous winds of our English latitudes can form an adequate notion. In the Pacific their general character is the same; but they are less strong, less steady, and, as has been already said, are to the south of the Line often very broken for months together. In the South Atlantic the Trade is stronger than in the North. As the result of the comparison of many logs, Captain Maury estimates the average speed of a well-found ship in crossing the Trades of the Atlantic, with the wind abeam, or just abaft the beam, at eight knots in the southern hemisphere, and at six in the northern.* In the South Indian Ocean it is commonly stronger than even in the South Atlantic; and everywhere it is stronger in winter than it is in summer, in the South Indian Ocean attaining in winter often to the strength of a fresh gale.

On the western side of each of the great oceanic basins there is a more or less well-marked alternation of the winds in summer and winter. On the coast of Florida, in the Gulf of Mexico, in Texas, and in others of the Southern States, the wind, which during the winter

* Sailing Directions, vol. ii. p. 863.

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months blows almost constantly from the northward, during the summer blows no less constantly from the southward. An alternation precisely similar takes place every season in the China Seas, an alternation which our rich commerce and our recent wars with the Celestial Empire have rendered even more familiar, both to navigators and the general reader.

South of the equator, the change is very clearly marked on the coast and over the vast plains of South America. The Trade wind, which during the winter blows to the coast of Brazil, south of the parallel of 10° S., from about E.S.E., in the summer prevails from about E.N.E., or from a point even still more northerly. Inland, up the valley of the Amazon, where the Trade blows nearly due east, the change is to a wind which blows down the river, or from the west. Near the east coast of Madagascar the wind in summer blows from the north or north-west, and in the Mozambique Channel from between north and N.E.; whilst in the winter the Trade blows fresh from the south-east, or, in the narrow channel, from the south-west. There is a similar change on the east coast of Australia, which is shown with sufficient distinctness by a comparison of the numbers of polar and equatorial winds observed in the different seasons, although the unsteady nature of the winds of the western part of the South Pacific renders it less strongly marked there than in other places.

And wherever this alternation is found, the winter, or polar wind is for the most part a steady pleasant breeze, freshening at times into a moderate gale, accompanied by fine clear weather; the summer, or equatorial wind, blows fitfully and in squalls, is unpleasantly sultry and moist, is accompanied by heavy rain, thunder and lightning, and is frequently interrupted by the most violent storms of which we have any knowledge.

The Basin of India and the Indian Ocean north of the Line is distinguished from the other great basins which we have just been considering, by the fact that this alternation of the winds is experienced over its whole area. The polar or northerly wind blows during the winter; in places with very marked casting, as on the coast of Arabia; in places with very marked westing, as in the plains of India and in the valley of the Ganges; and in some places, as on the Malabar and Coromandel coasts, the northing itself is the most marked feature of the direction; but everywhere it blows steadily and brings fine weather. The wind of summer, which, with a similar variation of direction in the different parts of the basin, is for the most part a wind from the south, has all the disagreeable qualities of the other summer equatorial winds which have just been mentioned. During its season, the weather is bad, heavy rain is almost continuous, squalls are frequent, and violent storms not uncommon; and, in short, the characteristics of the monsoons, or alternate winds which prevail over the whole of the Basin of India, do not differ in any noteworthy respect from the winds of those easterly coasts and countries where a similar alternation is experienced every summer and winter.

In both hemispheres, to the north or south of the parallel of 35° or 40°, a strong westerly wind blows with great constancy all round the world. In the southern hemisphere, more particularly, it blows with a persistence little less than that of the Trade winds, but with a strength which, although fitful, is very much greater. From a fresh, strong breeze, it rises very frequently into a violent gale, and, as such, blows for days together; the mean direction being very nearly west, from which it seldom varies more than a couple of points on either side. South of the Atlantic, south of the Indian Ocean, south of Australia, in the higher latitudes of the Southern Pacific, and to the southward of

Cape Horn, we find it still the same—a westerly gale, whose strength and constancy combined have enabled Australian clippers to make passages which seem to border on the fabulous. In the northern hemisphere it has not the clear range which it has in the southern; but there too it prevails in the most decided and marked manner. Alike in the Atlantic and Pacific; in North America, west of the Rocky Mountains; in the Eastern States; in European Russia and Germany, and in Northern Asia, we find the same predominance of westerly winds. If they fail on the eastern side of the mountain ranges which run towards the north and south,—of the Rocky Mountains, of the mountain system of the west of Europe, or of the Ural Mountains,—they soon recommence, and sweep across the countries on the east of these, with the same fresh and occasionally boisterous strength as across those on the western side.

In each of the oceans, between the westerly winds and the Trade—that is to say, about the latitude of 35° or 40°, N. or S.—there is a large area where the winds are very unsettled, blowing unsteadily from all points of the compass, or alternating with wearisome calms. Many geographers represent these regions as extending, east and west, from one coast to the other; for this there is no authority whatever; and it is quite certain that the polar winds on all the west coasts, whether of Portugal, Africa, and California in the northern hemisphere, or of Africa, Chili, and Australia in the southern, blow fresh across the belts shown on most anemological maps as the "Calms of Cancer," or "of Capricorn," and form, most distinctly, a junction between the westerly winds and the Trades; whilst on the western sides of the oceanic basins, equatorial winds are almost constantly met with in those latitudes, and, by the gradual veering of the Trades, seem to be another connecting link, or series of connecting links, between the

two great atmospheric currents—the easterly, or Trade winds, and the westerly winds of the higher latitudes.

These opposite currents of air, each extending over so many degrees of latitude, and prevailing, as far as we can determine, with comparatively trifling exceptions, right round the world, may be confidently assumed as the most direct effects of the causes which produce the great movements of the atmosphere; and the very remarkable steadiness of the TRADE WINDS, more particularly in the North and South Atlantic,—seas with which the traffic of the whole civilized world has made us most intimately acquainted,—turned, at a very early period, the attention of scientific inquirers to an especial consideration of them, as the primary manifestations of these effects, and led to the gradual construction of the following theory,—a theory which has, for the last hundred years, been very generally accepted as affording a satisfactory explanation of the principal phenomena in anemology.

## SECTION II.

### HADLEY'S THEORY, AND ITS MODIFICATIONS.

THE air within the tropics, being heated to a temperature considerably in excess of that of the air nearer the poles, becomes specifically lighter, and rises—that is to say, is forced up by the pressure of the adjoining colder and heavier air. As this colder air comes within the more direct influence of the sun's rays, it also is heated, and in turn rises, giving place to fresh volumes of the denser air of the higher latitudes: this succession, recurring without pause, is equivalent to a wind from the north or south, towards the equator; and if the earth were at rest, with the sun, as the source of intertropical heat, revolving round

it, and if the earth's surface were uniformly smooth, consisting of one vast uninterrupted ocean, such winds from north and south would be everywhere experienced.

On this supposition, the air continually pressing in towards the Line from the colder regions without the tropics, and forming, as it becomes heated, a continually ascending current, must, on attaining some certain height depending on the relative degrees of temperature, cease to rise; and, being every moment added to from below, must flow off to the northward or southward, forming, in each hemisphere, an upper current, streaming from the equator towards the poles, in a direction exactly opposite to the wind blowing lower down. By the time that it has arrived at the parallel of 30°, the air of this upper current, being in great measure cooled, becomes so heavy as to sink to the surface, where a large proportion of it is again drawn, or pressed, in towards the Line; but by far the greater quantity forces itself towards the poles, as direct equatorial winds in the temperate zones.

Since, however, the earth revolves on its axis from west to east, every point in the earth's surface thus describes round the axis, once in twenty-four hours, a circle, which is exactly represented by the parallel of its latitude. These parallels of latitude rapidly diminish in size, from the equator to the pole; at the equator, one-twenty-fourth of the whole circumference, or the space a point on the surface of the earth moves through in one hour is 900 nautical miles: in other latitudes this space is considerably less; on the parallels of 15°, 30°, 45°, and 60°, the distances which a point on the surface of the earth moves through in an hour are 869, 779, 636, and 450 miles respectively, and in higher latitudes these distances diminish still more rapidly.

A particle of air, then, resting in any given latitude, has the rate of motion of the points of the earth in that latitude

impressed on it: a particle of air resting, for instance, on the earth at the parallel of 30°, moves towards the east, with the point of the earth on which it rests, at the rate of 779 miles an hour, and will retain that rate of motion, even if taken away to another parallel, where the velocity of the points of the earth's surface is greater or less; if it is transferred to a lower latitude, as to the parallel of 29°, it will move slower, and if to a higher latitude, as to the parallel of 31°, it will move faster than the points of the earth on that parallel; and whenever the velocity of the air is in excess of the velocity of the earth's surface, there is a relative resultant velocity, that is, a sensible motion towards the east; and if its velocity is less than that of the earth's surface, there is a sensible motion towards the west.

Thus, then, air moving towards the equator, drawn in by the continuous rarefaction of the tropical atmosphere, instead of making itself felt, in the respective hemispheres, as a wind from due north or south, becomes a sensible wind from the north-east or south-east; and the winds so produced are the NORTH-EAST and SOUTH-EAST TRADES.

On the other hand, air overflowing from the equator, where it has the velocity of the earth's surface at the equator, moves into higher latitudes, and is a wind from the south-west or north-west, at first as an upper current and afterwards as a surface wind.

Again, where the air carried southward to the equator, in the northern hemisphere, meets the air carried northward in the southern hemisphere, the two horizontal currents, coalescing, form one ascending current: the northerly and southerly Trades clash, counterbalance each other and lose their motion towards the south or north: the air of each, being rarefied by heat, rises, and there is no sensible horizontal current or wind. Where this

meeting takes place is a region of calms. It is marked in the maps as THE REGION OF EQUATORIAL CALMS.

Where the air, which, having overflowed from the upper regions of the equatorial calms, has been carried northward or southward, sinks again—that is to say, between the parallels of 30° and 40°, the descending current, forcing its way into the lower atmosphere, checks whatever motion it may have at that point; and, whilst a large portion of the descending air is drawn in towards the equator to supply the Trades; whilst the greater part of it forces its way towards the pole, forming the south-westerly or north-westerly winds of higher latitudes; at the point where the descent and the division of the descending current takes place, there is another belt in which the horizontal current is neutralized—a belt of calms. This belt is in both hemispheres, and is marked in all maps that attempt to pourtray the motions of the atmosphere, as, in the northern hemisphere, "THE CALMS OF CANCER," in the southern hemisphere, "THE CALMS OF CAPRICORN."

This is the theory, which, faintly and imperfectly outlined by Halley towards the end of the 17th century,* was first clearly stated by George Hadley about fifty years later;† and which has, in the main, been adopted by all our leading meteorologists, although some of them have

* Philosophical Transactions, 1686.

† Philosophical Transactions, 1735.—This ingenious paper by George Hadley is—in the common opinion of even scientific readers—attributed to his brother John, who by his introduction of the reflecting quadrant rendered his name more familiar. Although John Hadley, as Vice-President of the Royal Society, must have been a man of considerable ability, it is curious to note that his fame, in the present day, rests almost entirely on the work of others. The quadrant, still known as "Hadley's," was invented and described in complete detail by Sir Isaac Newton years before Hadley laid it before the Royal Society in 1731; and the theory of the Trade Winds belongs altogether, as I have said, to his brother George.—See Biog. Univ. *s.n.* Hadley.

formed different opinions on certain points of detail. Captain Maury, in particular, has enunciated a theory to which his reputation as an anemologist necessarily gives a great weight.

He conceives that a particle of air, forming, of course, a constituent unit of a large volume, leaving the north pole, travels southward, in an *upper current*, till it reaches the parallel of 35° N., or thereabouts, where it descends and continues its southerly course as part of the Trade wind; but whether in the upper regions, or on the surface, the direction of its motion, owing to the rotation of the earth, as already explained, is from the north-east. By the time it arrives at the equator, it has become so far heated, that it rises, but without losing its onward motion, and continues its course towards the south, again in an upper current; but, as it is now travelling from a low latitude to a higher, its sensible direction is from the west of north, a direction which it still preserves when, about the parallel of 35° S., it again descends, and forms part of the surface wind; as such, it continues its way towards the south pole, in the neighbourhood of which it rises, and, by the ceaseless motion of all the particles of air, in a similar course, and by the rarefaction of the tropical atmosphere, is drawn again towards the equator. From the south pole it moves in a south-easterly upper current, descends about the parallel of 35° S., holds its way towards the line with the south-east Trade, rises, and continuing northwards, is part of the south-west upper current of the northern tropical regions, and of the south-west wind of the northern temperate zone, after its descent near the parallel of 35° N. It thus, after a complete circuit of the earth, returns to the north pole, and recommences its round, as before.

There is, therefore, at the equator, and near the parallels of 35° in each hemisphere, a crossing of the

south-going and north-going currents. The two streams, both ascending, or both descending, strike each other at an angle of nearly 90°; and, without to any material extent mingling, pass through each other, and pursue their course, each in its own former direction. As the streams are continuous, this crossing is always going on; at the crossing places there is no horizontal current or wind; and there are thus formed three distinct belts of calms—the CALMS OF CANCER, or the HORSE LATITUDES; the EQUATORIAL CALMS, or DOLDRUMS; and the CALMS OF CAPRICORN,—each extending round the entire world.

The reasons which Captain Maury sets forth at great length as establishing this rather complex movement of the atmosphere, and more especially the crossing which he describes as taking place at the belts of calms, will be discussed at a later period. It may here, however, be remarked that, so far as actual observation goes, there is absolutely no reason to suppose that two currents of the same, or not very different fluids, meeting each other at an angle, whether that angle is great or small, ever do cross in the way in which the ascending and descending currents are here said to cross. We cannot, perhaps, say positively that two fluids so meeting cannot so cross; but whilst we have no instance in which such a crossing has been actually observed, it certainly cannot be received as even an allowable hypothesis, still less as an acknowledged fact.

This rejection of the details of Captain Maury's theory does not, however, in any way affect our acceptance of the broad principles on which it is founded, and which are essentially the same as those of Hadley's theory, already stated. I pass on, therefore, to offer a fuller and more detailed explanation of these principles, and to examine as to how far they do really account for the observed anemological phenomena, which have been described in the

previous chapters; and in doing so, briefly enunciate them, thus:—

I. The direction of the TRADE WINDS is from the respective poles, north or south, towards the equator; and the direction of the winds of the temperate zone, frequently called the COUNTER TRADES, is from the equator towards the poles; and this northerly or southerly direction is, in each, due to the relative excess of temperature at or near the equator over that in higher latitudes.

II. The direction of the TRADE WINDS is also from the east, and the direction of the COUNTER TRADES is from the west; and, in both cases, this is due to the rotation of the earth.

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## SECTION III.

### HEAT, CONSIDERED AS A CAUSE OF WIND.

ALMOST all substances have the property of expanding—that is, of increasing their bulk when heated, and of contracting, that is, of diminishing their bulk when cooled; to this rule there are but few exceptions, which in no way affect the subject of our present inquiry.

This peculiar property of matter is so well known, and enters so intimately into our common experience, that we are almost liable to overlook the enormous power which it has as a mechanical agent, notwithstanding the requency with which it is made use of. The way in which a blacksmith binds the iron tires on to cart wheels is one familiar instance of this. The iron band, being made rather small, is heated until, by the expansion of the metal, it becomes large enough to admit of its being put on to the wheel easily: it is then allowed to cool, and in cooling resumes its former size, binding, as it does so, the parts of the wheel together with a strength and uniformity of strain which can be got in no other manner. A similar method has

been tried for strengthening cast iron guns, by shrinking on bands or envelopes of wrought iron; and in the heavy ordnance, which has within these last few years been introduced into our Navy and Artillery, the several folds of metal are all successively shrunk, in precisely the same manner, on to the innermost tube.

Old houses, whose walls have a tendency to fall or bulge outwards, are very often secured by another application of the force with which metal contracts. Iron rods are passed through the house from one side to the other, and large washers with strong nuts put on the ends on the outside of the walls: the iron rods are then heated by rows of little lamps placed underneath them; and the expansion, produced by the heat, lengthening the rods, causes the ends to protrude further through the walls; the nuts on the outside are screwed home, and as the rods cool, the strain of contraction pulls the walls, which bear on the large washers, into their proper place, with a force which, in its nature, is irresistible. Something must give to it; the walls must move, or the rods break. This plan is very common in some parts of the country; and the washers, shaped generally like rather straggling letters S or X, may be often seen on the walls of rickety-looking houses, and might easily be mistaken for a quaint old-fashioned style of ornament.

The common pendulum clock affords a simple instance of the manner in which this property of metals affects our every-day life. When the pendulum is lengthened, it swings more slowly, and the clock goes slower; faster, on the other hand, when it is shortened. It is in this way that the clock is regulated; the ball of the pendulum screws up or down, or else moves on a stiff slide, so that it can be raised or lowered according as the clock is losing or gaining. Any change of temperature alters the regulation: as summer comes on, the heat expands the metal

rod—that is to say, lengthens the pendulum, and the clock loses; in winter the rod contracts, or becomes shorter, and the clock gains.

Watches are affected by the change of temperature in a similar manner. The balance wheel, which is the fly-wheel of the machinery,—and an extremely heavy one as compared with the small size and delicate nature of the gear it regulates,—becomes larger and swings more sluggishly in hot weather, and the watch loses; and, on the contrary, it is smaller and more lively in cold weather, and the watch gains. This is necessarily the case, as far as the mechanical adjustment of the watch is concerned; occasionally, however, the oil which lubricates the works, if of inferior quality, becomes viscous from cold—half-frozen in fact—and either stops the watch or makes it lose. As the oil which all good makers now use does not freeze except at very low temperatures, this inconvenience ought never to be experienced; but the enlargement of the balance wheel, depending on an essential property of metals, is unavoidable; and the chief peculiarity of chronometers, which are merely watches so constructed as to preserve a uniform rate under all ordinary temperatures, is a balance wheel, which, by an ingenious combination of metals of different expansive powers—steel and brass for instance—alters its shape instead of its effective radius. Whilst all metals possess the property of expansion and contraction to a greater extent than other solids, they differ very considerably amongst themselves in the relative measure of it; brass expands very much more than steel, silver than platinum; and it is this peculiarity which has been taken advantage of, in the construction not only of chronometers but of many other valuable instruments.

The breaking of a glass tumbler when hot water is poured into it, is a direct consequence of the expansion caused by the heat. Heat passes along or through glass

with great difficulty and with extreme slowness; it takes a very sensible time to penetrate from the inside to the outside of the tumbler, and the inside surface expands before the outside feels the influence of the heat at all. The result is a violent riving asunder of the particles; an accident which is more likely to happen with a thick tumbler than a thin one, owing to the greater time the heat takes to penetrate to the outer surface. Very thin glass is not apt to break in this way; and with a little care, water may be boiled easily enough in a thin glass flask over a spirit lamp.

The common thermometer, the well-known instrument for measuring the relative values of different temperatures, is founded entirely on this property of expansion; as the mercury or alcohol in the bulb is heated, its volume becomes greater, and it rises in the tube; as it cools, it falls; for fluids no less than solids are subject to this law. and amongst fluids the great expansive power of gases is pre-eminent. Air, the most common of all gases, or combinations of gases, expands enormously when heated; a bladder only half blown up will, if placed before a fire, swell till it has all the appearance of being well blown, and, if kept before the fire, will burst with a loud crack, so great is the expansive force which even that small quantity of air is capable of exerting. Another instance of this will be familiar to every football player; a ball may be blown up in a warm room till it is as tight and hard as possible, but on the field is quite slack and dead. This is in consequence of the contraction of the air with which it is filled, due to the comparative cold out of doors. Foot-ball players know this well enough by experience, and take care to have the ball blown up in a cold room or in the open air.

As bodies expand by heat, their relative weight becomes less: the absolute weight remains the same, whilst the

volume increases. If a cubic foot of any substance become by expansion two cubic feet, it is quite clear that, since the two cubic feet weigh exactly the same as the one cubic foot did, the weight of one cubic foot of the expanded substance is just half the weight of the original one cubic foot; and, generally, a volume of a substance expanded by heat is lighter than the same volume of the same substance at a lower temperature. When therefore fluids are heated, the hottest parts, or those most expanded, rise to the top if they are not at the top; and if they are at the top, stay there. This is very clearly illustrated by boiling water in a glass flask: the fire underneath necessarily warms the lower part first; this rises to the top in a number of fine upward currents, whilst the colder, heavier water at the top sinks to the bottom. This in turn becomes the hottest, and rises, so that a continuous interchange between the top and bottom of the water goes on, and can be clearly seen through the transparent sides of the flask.

Similarly, if warm water be gently poured into a basin partly full of cold water, it will lie on the top for a long time without mixing with that below; but if this is reversed, if the cold is poured on top of the warm, it immediately falls through it, and though in passing through the warm water, part mixes with it, and the whole is to a certain extent heated by the close proximity, still, if left quite undisturbed, a cool stratum will form itself below and separate from the warm, and may be distinctly felt on plunging the hand to the bottom.

In exactly the same way as other substances, whether solid or fluid, does air become relatively lighter when expanded by heat. The common little fire balloon is a familiar instance of this: the air contained in the paper covering is expanded by the heat from the burning spirit, and a considerable portion being expelled, the rest is

specifically lighter than the air of the surrounding atmosphere. It therefore rises, and does so with force sufficient to carry up with it the paper bag and the flaming sponge.

Another and somewhat disagreeable illustration of the truth of this general principle may be easily found in the gallery of a theatre. The air, heated by the gas and the exhalations from thousands of spectators, rises to the ceiling, carrying with it the numberless impurities with which it is loaded; thus, while the lower part of the house may be pleasant and cool, the upper part is frequently filled with a hot foul air—an evil serious enough, one would imagine, to repress the energy and choke the pleasure of even the most determined playgoer. The "gods" endure it, however, and are noisily merry and jolly under circumstances worthy of Mark Tapley himself.

I have no wish to enter here into any description of delicate experiments on expansion by heat. Beautiful and interesting as many of these are, the necessities of my subject do not require me to bring forward other examples than those which come within the observation of every-day life; and there are few boys who do not know how to send up a fire balloon, few men who have not at one time or another been half stifled in the gallery of a crowded theatre.

In every instance in which this rising of heated air is observed, it must be borne in mind that it is due, not to any innate tendency to rise, bestowed on it by the heat and expansion, but to its being made by their action specifically lighter than the surrounding air, and being consequently *pushed up* by the denser air which forces its way in underneath it. If a piece of cork be thrust down to the bottom of a vessel of water, it will jump to the top as soon as it is left free, not in consequence of its own disposition to rise or of any repulsion exerted by the earth, but in consequence of the comparatively heavy water violently

shoving itself underneath it. The law of gravitation is the same for both bodies; the cork is attracted towards the earth in precisely the same manner as the water, but it is so in a very much less degree, and the difference between the two attractions is the force which pulls the water down, or virtually pushes the cork up. It is the same with two bodies of air of different specific gravities; the heavier is pulled down and under the lighter; it takes the place of the lighter by a motion which is more or less sensible, and which does occasionally produce very easily observed results.

In winter, sitting in a well-warmed room, with a roaring fire throwing genial heat all around, we often find our feet unpleasantly cold. This is due to the heavy air outside forcing itself through the narrow chink at the bottom of the door, and spreading itself out over the floor as a cold stratum; so that, notwithstanding the general warmth of the room, we are really sitting with our feet in a bath of cold air.

Under similar circumstances we may often hear a heavy, droning noise at the window; it is the vibration caused by the cold air forcing itself through the chinks; and in both cases, as the cold air enters below, the hot air already in the room must get out somewhere; a good deal goes up the chimney, and some, no doubt, escapes through chinks in the door or windows. If the door be opened, the rush in of cold air is most uncomfortable, and as long as the door is open the cold air continues to come in, though not with the same violence as at first, when there was greater difference between the temperatures of air inside and outside the room. Regular currents establish themselves, and it will be found that whilst the cold air is coming in below, the heated air is very steadily streaming out above. This opposition is quite perceptible to the hand, but it will be seen very distinctly by holding a

lighted candle in the doorway, alternately near the bottom and the top. In the first position the flame and smoke will bend very decidedly into the room, in the second they will as decidedly bend out from it.

The principle on which coal mines are ventilated is founded entirely on this property. It is well known that the air in these mines becomes excessively foul, not only from the many impurities incidental to a place where hundreds of men and animals live and work, from the smoke of candles, and the frequent explosions of gunpowder in blasting, but also, and principally, from the escape of pernicious gas, whether it be "choke-damp," which is fatal to life, or "fire-damp," which explodes with awfully destructive violence. It is therefore in the highest degree necessary that the air should be continually changed, that the foul air should be removed before it becomes absolutely poisonous, and that fresh air should be substituted. This is effected by the apparently simple means of keeping a huge fire constantly burning at the foot of the shaft. Most coal pits have now two shafts at least; but in the rare instances where there is only one, it is divided into two by a wooden partition running vertically down the middle of it. At the bottom of one of the shafts, or one of these divisions, is the fire, which day or night is never allowed to go out, or even to burn low. The tremendous heat which it gives out causes the air all around it, and especially in the shaft above, to expand, and to rise, pressed upwards by all the rest of the air which is at the bottom of the pit. Fresh air is drawn down the other shaft, or the other division of the same shaft, and is led by a careful and systematic arrangement of screens or bulkheads, so as to be obliged to traverse all the avenues of the mine, or those which it is, for the time being, more especially wished to ventilate, before it can reach the fire, towards which it necessarily gravitates. It sweeps along

these avenues with a force which, though capable of regulation, may be made as strong as that of a violent gale of wind, and in its passage carries before it all the atmospheric impurities which have to be removed. It is, in fact, like flushing the sewers of a town with a stream of clean water, which, descending to the sea, carries with it mud, filth, rats, everything which it is wished to remove. In a similar manner does this strong current of air cleanse the passages of the mine, and sweep every impurity into the roaring fire, where they become expanded and forced up the chimney-like shaft into the free space above. No illustration of the power of heat to produce wind can be stronger than this; and it is impossible for any one who has experienced—as I have repeatedly done—or who can understand the extraordinary violence to which this current of air frequently attains, to doubt for a moment the very great influence which heat must exercise on the movements of the atmosphere.

We must therefore consider it as a well-established fact that where heated air rises, the colder denser air takes its place with a motion whose direction approaches more or less nearly to horizontal. Such a motion, when on a large scale, and when the velocity is sensible, is WIND; and it is such, that Hadley's theory, already enunciated, describes as being found on the very largest scale in the Trade winds—winds, so it is said, blowing constantly from the higher latitudes of each hemisphere, where the air is colder and denser, to the intertropical regions, and especially towards the sun's parallel of declination, where the air is warmer and more rarefied.

To this application of the principle, which I have just been illustrating, there are, however, I conceive, several very grave objections. The gravest is also the one easiest to state. It is simply that the Trade winds do not blow

towards the hottest part of the globe; and since it must be conceded that heat, if the motive power which produces the Trade winds, is also capable of producing other prevalent winds, it is an objection almost equally strong, that, as a rule, whether in the Trade wind region, or out of it, prevalent winds do not blow towards the places where the temperature is the highest, and in those exceptional cases where they do, they do so in such a manner as to show that some agency widely different from the expansion of the air by heat is the propelling force.

The temperature of the air over the sea, on or near the equator, is seldom much in excess of 82° F.; and 85° F. is a limit to which it has probably never been known to attain. At sea, the decrease from this temperature, as we approach the poles, is tolerably regular. On shore it is not so. The countries bordering on the equator are nowhere distinguished for their excessive temperature. Du Chaillu in the western, Speke and Baker in the eastern districts of Equatorial Africa, Bates in Equatorial America, all competent observers and credible witnesses, agree that the heat was by no means remarkable. In Eastern Africa, indeed, partly from the elevation of the land, although not more than from two to four thousand feet above the sea, but principally from the heavy and almost continual rains, the climate is described as temperate or even cold. In Western Africa and in South America the air, stagnant amongst the dense primeval forests, is exceedingly moist, unhealthy, and disagreeable, but the heat is not itself excessive.*

On the other hand, in no part of the world is greater natural heat experienced than in the deserts of North Africa during the months of June, July, and August. These deserts extend over fifteen or twenty degrees of

* SPEKE: Source of the Nile.—BAKER: Albert Nyanza.—DU CHAILLU: Equatorial Africa.—BATES: Naturalist on the Amazons; *passim*.

latitude north of the parallel of 10° N., and, without any interruption worth mentioning, reach almost from the seaboard of the Atlantic to the very banks of the Nile, or through nearly forty degrees of longitude. Over the whole of this enormous area the thermometer during the summer months stands extremely high. Often, for many consecutive weeks, it does not fall below 90° F., whilst in the afternoon it very commonly rises to 110°, 115°, or 120° F. Higher degrees, which seem almost fabulous, have been noted by some of our most distinguished explorers. At Murzuk, in 26° N. and 14° W., Captain Lyon and Mr. Ritchie repeatedly found the temperature in the shade 130°, and on two distinct occasions 133° F.*

Many attempts have been made to explain away the statement of this extraordinary temperature. Dr. Barth says that at Murzuk he experienced nothing at all approaching to it; and thinks that possibly the thermometer was carelessly placed, and gave the temperature of the heated earth. There is no foundation, in evidence, for this opinion; and the very remarkable nature of the observation, though it may call for caution, is not, in itself, sufficient to warrant us in disbelieving the plain testimony of careful witnesses, of whose good faith there can be no doubt. Humboldt suggests that it may have been caused by a quantity of fine, almost impalpable, sand floating in the air. It may have been so. The nature of the country round Murzuk, described as extremely arid, and the frequency of violent sand storms, seem to render it far from improbable; but in very distant parts of the world, and in situations where there seems no reason to suppose that the air was loaded with sand, other observers have noted temperatures as high. Captain Sturt, for instance, the celebrated Australian explorer, has mentioned that on the 11th November, in the neighbour-

* LYON: Travels, etc. pp. 356, 357.

hood of Cooper's Creek, a thermometer carefully placed in the fork of a tree, "sheltered alike from the wind and the sun," burst at 127° F., the highest point of its range.*

Of the very great heat which prevails over North Central Africa, there can however be no doubt; and 100° F. may, without the least approach to exaggeration, be assumed as the mean temperature during the months of June, July, and August, when the thermometer by night seldom falls below 90°, and by day very commonly rises to 120° F. Compared with such heat, the 82° F. of the equatorial regions of the Atlantic Ocean is but trifling; and it is perfectly clear that a wind produced by the expansion of the air by heat, blowing from a place where the mean temperature is 70° or thereabouts, will blow towards the place where the mean temperature is 100°, in preference to one where it is only 82°; will blow from the Atlantic in the parallel of 30° N., not towards the equator, but towards the interior of Africa.

Such a wind we do not find. There is no trace whatever of an inclination of the atmospheric current, which prevails down the west coast of Africa, towards the land: there is no appearance of any great indraught of the cool air of the ocean towards the burning regions of the Continent. A glance at the map will show that such an indraught would be, in effect, a westerly wind in the eastern part of the Atlantic, between the parallels of 30° and 15° N. In that part of the ocean, the Trade wind blows very steadily from about N.N.E. Some eminent writers have given it as their opinion that in this very part the Trade is more easterly than elsewhere,† and though this is an

* HENRY BARTH, D.C.L.: Travels and Discoveries in North and Central Africa, vol. i. p. 166.—HUMBOLDT: L'Asie Centrale, vol. iii. p. 174.—STURT: Expedition into Central Australia, vol. ii. p. 90.

† Captain BASIL HALL: Letter on the Trade Winds, in Daniell's Meteorology, vol. i. p. 255.—Sir JOHN HERSCHEL: Meteorology, § 61.

error founded on imperfect observations, and induced possibly by not sufficiently attending to the variations in the direction of the wind which follow changes in longitude, even on the same parallel of latitude, it is, nevertheless, quite certain that it does very frequently blow off the land. Professor Dove considers that the prevailing northerly direction is a sign of the influence of the heated atmosphere of the desert, the great atmospheric current being drawn aside from its natural direction by a secondary force which modifies, though it does not materially alter, the effect of that which is the prime agent in producing it.* But the difference between the temperatures of the air over the sea and over the land, on or about the parallel of 25° N., is far greater than the difference of temperatures at sea between the air in that latitude and the air further to the south; and if heat caused the wind, it would act to draw the air *eastwards*, not *southwards*.

The evidence of the Admiralty wind charts, or of Maury's pilot charts, is conclusive as to the direction of the Trade in this part of the ocean; but their testimony is by no means new, although ignored by many who have preferred their own isolated experiences or fancies to the accumulated evidence of many witnesses. Dampier placed it on record nearly two hundred years ago. He says: "That part of Africa which lies between Cape Verde in 14° North and Cape Bayedore [Bojador] in 27° has commonly northerly winds, or between the N. and N.E. very fresh gales; therefore our Guinea ships, bound to Guinea, strive to keep near that shore, and ofttimes make the Capes, and being to the southward of Cape Blanco, which lies in latitude about 21°, they are sometimes so troubled with the sand which the wind brings off shore, that they are scarce able to see one another. Their decks are all strewed with it, and their sails all red, as if they were

* DOVE: The Law of Storms, p. 68.

tanned with the sand that sticks to them, it being of a reddish colour."*

The winds of the North Atlantic have been more carefully observed and more exactly mapped than those of any other ocean; the evidence regarding them is thus more thoroughly reliable, and more readily available than it is for other parts of the world; but we have still quite sufficient proof that the west coast of the great African desert is an example of the rule, not of an exception, and that nowhere, under circumstances at all similar, do we find any marked indraught to the interior of heated continents. Central Australia is perhaps, after Northern Africa, the largest area over which the air is in summer raised to a very high temperature; but the Trade wind of the South Indian Ocean pursues its course steadily along, and nearly parallel to the west coast; and whilst, for the most part, it turns away towards the mid-ocean as a south-easterly wind, a large branch of it turns round the North-West Cape, and blows in the narrow seas from S.W. or West, but seldom from the N.W. or N.N.W., the direction which an indraught to the interior would cause it to assume. In a similar manner, the winds on the south coast of Arabia do not appear to be in any degree acted on by the burning heat of the Arabian desert. In the summer months the South-West Monsoon, in its full strength, blows along that coast with a singularly constant direction from between S.W. and W.S.W.; and though it is very frequently asserted that the South-West Monsoon is caused by the high temperature which prevails over the plains of Hindostan and the deserts of the Punjaub, it is impossible to avoid noticing that such an explanation of this periodical wind involves the supposition that the air over the western part of the Arabian Sea, uninfluenced by the extreme heat and immediate

* DAMPIER: Voyages, etc. vol. ii. part iii. p. 15.

neighbourhood of Arabia, is attracted strongly—nay, violently—by a far less degree of heat more than a thousand miles distant.

If heat be the cause of the Trade winds, if a difference in temperature of 10°, 15°, or 20° can cause such a steady flow of air from the parallel of 30° towards the equator, a still greater difference in temperature over large and contiguous areas—a difference of 30°, 40°, or even 50°—must, in precisely the same manner, cause a still stronger flow of air towards the warmer region. We have seen that it does not towards the Sahara or Central Australia, areas vast even in comparison with the adjacent oceans; that, however great may be the attraction towards these regions, it is not sufficient to overcome or even to neutralize the force which compels the oceanic air to move towards the equator. Now, a greater force necessarily overcomes a less which is opposed to it, and prevents motion in the direction of the less. In both the cases I have named, the attraction due to expansion by heat is much greater towards the east than towards the equator; but it does not prevent—apparently does not materially modify—the motion towards the equator. We are driven, then, to the conclusion that the force which tends to the equator is greater than the force which tends to the east; and that that force is therefore not the attraction due to expansion by heat.

Again, if we leave the region of the Trades we find a westerly wind blowing over the northern parts of the Atlantic, of Europe, and of Asia. During the summer months, the wide plains of this part of the old continent have a warm genial climate; the air over the land, near the parallel of 50° N., is then undoubtedly warmer than the air of the Atlantic Ocean in the same latitude. In winter, the relations are reversed: the thermometer in Russia, or Siberia, sinks to zero, and very far below it;

in the Atlantic it stands at a mean of 40° or 45° F.; and it is precisely at this season of the year that, in direct opposition to the force which would attract the cold air of the continent towards the place of the warm air of the ocean, the westerly winds blow with their greatest constancy and strength; whereas, in summer, when the difference of temperature might be expected to give them additional force, they die away to a light breeze, often to a scarcely perceptible breath.

In the North Pacific there is the same marked strength and persistence of the wind from the warmer towards the colder region: the winter climate of Sitka and all the neighbouring coast, from Vancouver's Island northwards, is softened by a moist, warm wind, blowing in from the south-west, which in summer loses both its force and regularity. Nothing can be more certain than that difference of temperature does not produce these westerly winds, for they blow in a direction exactly opposite to that which the difference would cause. And not only in these instances, but in almost every place in the known world, do we constantly meet with *warm winds*, forcing a quantity of heated air into the place of air comparatively cool. A *warm wind* is a thing which has come under everybody's observation, whether at home or abroad; and it is scarcely necessary to call particular attention to such very marked examples of it as the Scirocco of the Mediterranean, the Hot Wind of New South Wales, or that burning wind which many of us have felt between the Canary and Cape Verde Islands.

And summing up the several steps in the argument, which have just been detailed, since a difference in temperature of 40° or more, is not capable of producing an easterly wind from the northern part of the old continent to the Atlantic; since a similar difference of 40° is not capable of producing a westerly wind from the Atlantic to

the Great Desert of North Africa, or from the South Indian Ocean to Central Australia, I conclude that a comparatively paltry difference of 15° or 20° is not capable of producing a northerly or southerly wind from the vicinity of the respective tropical circles towards the equator, and that this difference is therefore not the cause of the northerly or southerly direction of the Trade winds.

Is this conclusion compatible with the very marked effects which, as has already been shown, heat is capable of producing? I think it is. In the illustrations of a sensible current of air produced by heat, it will be noticed that the current streams through a confined and narrow opening—through the chinks of doors or windows, through an open door, or, in the most important of all, through a series of narrow passages carefully regulated by screens and bulkheads; but when two volumes of air of different temperatures are in free contiguity, the interchange that takes place between them, although sensible in its effects, is so gentle that the motion itself is not perceptible. Thus, in a large room, warmed by a stove, the air immediately near the stove becomes heated and rises, its place being taken by colder air from more distant parts of the room. There can be no doubt that two currents of air are established—a cold lower one, towards the stove, a warm upper one from it. The air in the room is carried round in a circulation continuous and yet so gentle that, without careful observation, it would escape notice, or be noticed only by the effect it produced in warming the distant ends of the room. But if the room be divided by a partition into two, so that the air in one, where the stove is, becomes hot, whilst the air in the other remains cold, then, if a doorway between the two be opened, the rush of air from one to the other is very sensible, and is more clearly marked in proportion to the narrowness of the opening. In the

natural instances which we have been considering, there is no such partition or doorway. The communication is free and unconfined, whether from the interior of the continent to the ocean, or from the temperate zones to the tropical; and any interchange which takes place between the air of the respective regions, in consequence of the difference of temperature will, if we may consider the instance I have just given as analogous, be so gradual as to be imperceptible.

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## SECTION IV.

### The Influence of the Earth's Rotation on the Direction of Wind.

We have now to consider the second part of Hadley's theory, as enunciated above, and to examine into the extent to which the rotation of the earth is capable of modifying the direction of the Trade winds. I have already explained the manner in which it acts, and the tendency which it has to give an apparent easterly direction to a polar, a westerly direction to an equatorial wind. Of the existence of this tendency there can be no doubt. It is clearly established by the first principles of Dynamics; but the apparent direction from east or west which it would impart to a volume of air moving from the north or south would be an actual motion from east or west, relatively to the surface of the earth; and though the amount of this motion—the relative velocity—could be very exactly calculated if there were no friction between air and earth, or air and sea, the result so obtained would differ widely from the facts as they really are. For the friction between the two is very great, and in order to understand the effect of the rotation of the earth, it will be necessary to endeavour to form some estimate of its value.

The difference between the hourly speed of a point on the parallel of 30° and on the equator is 120 miles. If then a quantity of air were to be suddenly transferred, or were to move without friction, from the parallel of 30° to the equator, it would manifest itself there as a storm of unheard-of severity; wind, in the most violent hurricanes, seldom attaining a velocity of more than 100 miles an hour. Instead of such a wind, whose fury nothing could withstand, we find on the equator the Trade frequently dying away to the gentlest of perceptible breezes; more especially does it so die away in the Pacific, where the expanse of ocean is the widest and most unbroken, where the surface over which it moves is the smoothest in the whole world.

A velocity of 120 miles an hour is, therefore, annihilated by the friction during the passage of the air from the outer margin of the Trade winds; and since this friction is acting continuously, the natural inference is that it is sufficient to prevent the air whilst moving towards the equator from acquiring, at any point of its course, any very considerable velocity from the east. The air is continually receiving the impress of the velocity of the earth's surface at the point to which it is borne; and though, as long as it is moving towards the equator, it can never have absolutely the velocity of the point where it actually is, it can have the velocity of a point only a few yards further distant, and will appear to move as if it had started from such a point. There will of course be a motion from the east; but it will be so slight as to be quite imperceptible. It will be greater on the parallel of 30° than in lower latitudes, constantly decreasing till it becomes absolutely nothing at the equator; but quantities so exceedingly small as this is, could not possibly produce any sensible effect, much less an effect so very marked as the Trade winds.

The "easting" of the Trades, is however undeniable. I am perhaps then over-estimating the friction between the surface of the air and that of the earth or ocean. There can, however, be no doubt that the friction is very great, not only between the air and the land, between the air and the water, but also between the air in motion and the air at rest. The toy called an "Odorator," which is used to scatter scent about a room, acts entirely by means of this friction. It consists simply of two small tubes placed at right angles to each other, and so adjusted that the top of the one is on a line with the axis of the other. The former is long enough to permit of its being put nearly to the bottom of an ordinary scent-bottle; then, if the other tube be blown through, the scent or any liquid will rise to the top and be dispersed as a shower of spray. The friction between the current of air blown through the short tube and the surface of the air in the long tube is sufficiently great to rub off layer after layer from the top, till there is a sensible vacuum. Into this vacuum the liquid rushes, and the friction between the current of air and its surface tears off the minute particles which are thrown about the room. The effect is so quick, indeed, that it almost seems as if the whole body of air in the tube was drawn out at once, as a piece of string might be by a pin stuck into it and carried along horizontally; it is so quick, that by a sharp puff the liquid, instead of rising steadily to the top and being blown away, may be made to jump through the tube to a height of several inches. The Odorator is a pretty toy, and affords a very clear instance of the force of atmospheric friction; but an example can scarcely be needed by any one who has had opportunities of observing natural phenomena as displayed in a free Nature, or who has seen the wind tearing off layers of the earth or water as it sweeps along over their surface.

It seems to me, then, that Professor Dove overlooked or under-estimated the effect which friction must produce, when he described a current of air streaming towards the equator as necessarily assuming a direction more and more easterly; and, similarly, an equatorial current as becoming more and more westerly, the longer the motion continues.* This would very evidently be the case if there was no friction; but since the friction is very great, this easterly or westerly tendency cannot *accumulate* in the way he supposes. In this view I am borne out by the most distinguished of English meteorologists, who, reasoning on the continuous effect of friction, and the approximate equality in length of degrees of longitude in low latitudes, concludes that the Trade winds, far from becoming more easterly as they approach the equator, must, on the contrary, become more northerly or southerly, and in the immediate neighbourhood of the equator must lose their easting altogether.† And such he considers to be the change in the direction of the Trade winds, basing his opinion on the description of Captain Basil Hall, already referred to. Captain Hall's description is, however, applicable only to a part of that branch of the north-east Trade of the North Atlantic which is thrown off near the Cape Verde Islands;‡ but of this branch the larger part turns to the east, becomes in fact a north-westerly wind, clearly, in no way owing to the rotation of the earth; whilst the Trades generally, in every one of the great basins where they blow, have a very decided easterly direction on or near the equator.

I am, therefore, of opinion that the influence of the

* The Law of Storms, p. 8.

† Sir JOHN HERSCHEL: Outlines of Astronomy, § 243.—Meteorology, § 61.

‡ See his Fragments of Voyages and Travels, 2nd series, vol. i. p. 191, where he speaks of crossing the Line between 18° and 23° W. long.

rotation of the earth is not sufficient to produce the effects observed. It must give the Trade winds, considered as currents of air streaming towards the equator, a *tendency* to veer to the eastward; but a tendency which is practically annihilated by the enormous friction with which air in motion grinds over other surfaces, whether land, sea, or air at rest.

But there is another objection to this part of Hadley's theory, which seems to be in some respects stronger than this which I base on the great effect of friction. According to the theory, the "westing" of the westerly winds of the temperate zones is as essentially caused by the rotation of the earth, as is the "easting" of the Trades; the westerly winds are, in the strictest sense, COUNTER TRADES, they are the reflex of the TRADES. But these westerly winds are, in many parts of the world, *polar* winds, not *equatorial*. In many places their average direction does, no doubt, tend from the equator: at Greenwich Observatory, for instance, the mean of several years gives it as W.S.W.; on the coast of Norway, and on the north-west coast of America, it is also from the south of west. The westerly winds at the Cape of Good Hope are, as a rule, from the northward of west, and the winter gales at St. Paul's are also north-westerly. On the other hand, these westerly winds are very frequently, in some places most commonly, from the polar side of west. In summer, at any rate, north-westerly winds prevail all along the west coast of North America. Over all the northern part of the States and Canada the wind blows commonly from the north-west. On the western side of the North Atlantic, and to the north of about 45°, the westerly gales draw round to the northward of west, and frequently to nearly due north.* On our own coasts, the light pleasant summer

* Captain H. TOYNBEE: Rep. to the Met. Com. On the Meteorology of the North Atlantic, 1869, I p. 9, 11, etc. and Diagrams.

breezes are north-westerly; so are they on the coast of Norway. Even in winter, when the prevailing direction is from the south-west, winds from the north-west are very frequent; and in the great westerly storms, the wind constantly goes round to the north-west and blows its hardest from that quarter. The numerous abstract logs given by Maury,* whilst showing in high southern latitudes a decided preponderance of north-westerly winds, show also a very great frequency of south-westerly; on the south coast of Australia the prevailing direction is south-westerly, and on the Murray River, some 60 miles from its mouth, Captain Sturt, in February, met with a succession of gales from the south-west, against which—he says—we on several occasions found it useless to contend. I was satisfied, he adds, "that the influence of the south-west wind is felt even as far in the interior as to the supposed Darling, in consequence of the uniform build of the huts, and the circumstance of their not only facing the north-east, but also being almost invariably erected under the lee of some bush."†

Thus, almost everywhere in the temperate zones, even in those places where the prevailing direction of the wind is from the equatorial side of west, a wind from west, or from the polar side of west, blows very frequently; and whatever effect the rotation of the earth may have in causing an equatorial westerly wind, it is quite clear that it can have none in causing a polar westerly wind: neither, unless we suppose atmospheric friction almost entirely removed, can it cause a wind from due west to blow with a strong unvarying force across thousands of miles of ocean or of continent. And it is difficult to believe that the one wind owes its origin to a cause different from that of the other;

* Sailing Directions, vol. ii. pp. 629—678.

† Expeditions into the Interior of Southern Australia, during the years 1828—1831, vol. ii. p. 153.

that the motive power suddenly changes, as the wind veers through two or three points of the compass, and that too without, in any manner, changing its general character.

A similar veering is met with in the Trades, where the wind in the northern hemisphere blows from the south-east, or in the southern from the north-east. This happens frequently enough, not only towards the west sides of the different basins, where it is commonly said to be drawn in by the land, but in mid-ocean, where it is as clear of all continental influence as it is possible for air on the surface of the earth to be, and especially in winter, when the wind by doing so turns away from the sun's circle of declination. This veering of the Trade, in the open sea, though experienced occasionally in all the oceans, is most common in the South Indian Ocean, where for days together it hangs at E.N.E. Near the land, however, this turning away from the equator is the marked feature of the wind on the eastern shores of all the bounding continents. On the coast of Brazil, for several months together, the prevailing direction is decidedly from the northward of east. This is very generally attributed to the air being drawn towards the south by the heated plains of South America. It is a ready and convenient explanation of the phenomenon, but it cannot be the true one; for in South America there are no heated plains: neither in the basin of the Amazon, nor in that of the Paraguay and Parana, is there any excessive heat such as has been imagined; all modern exploration shows that the temperature, though of course tropical in its standard, is not extreme; and even if it were, we cannot allow that "heated plains" in South America could produce such a strongly-marked effect, when, in Africa, or Australia, or Arabia, they are incapable of producing any effect at all.

A similar bending towards the pole is experienced on

the coast of Florida and in the Gulf of Mexico. The Trade, veering through east, becomes a decidedly southerly wind, and for several months in summer blows steadily on the coast of Texas from between S.E. and south. This is, on the same principle as before, attributed to the heating of the Great Prairie. The air over the wide plain west of the Mississippi does, doubtless, in the summer attain a very high, often an extremely high, temperature, but still neither equal to, nor so permanent as, the high temperature of the Sahara; and, besides, when we seek for observations inland, we find the most absolute proof, that this south-easterly wind on the coast of the Gulf is not due to any indraught to the Prairie, although it certainly does blow towards it; for on the north-eastern side of the Prairie it blows away from it. The admirable system of meteorological observations, instituted by the United States' Government, gives us very exact information on this point. In the State of Missouri there is in summer a preponderance of south-easterly winds; at Fort Gibson the prevailing direction is between S. and S.E.; at Fort Atkinson it is the same; further north it becomes more southerly; at Fort Kearney it is S.S.W.; and in Minnesota it is due south.* Now, it is quite clear that if the Great Prairie could draw the Trade wind in from the Gulf of Mexico, it would not permit the air in the colder Minnesota to stream away from it. The air which comes over the continent on the coasts of Texas and Louisiana pours northward in an unbroken current, first from south-east, then from south, veering constantly towards the west as it increases its latitude, until it becomes merged in the westerly winds which prevail over the Northern States.

But the most marked instance of all is to be found in

* BLODGET: Climatology of the United States, p. 366.

the western part of the North Pacific. On the east coast of the Philippine Islands, the Trade wind in summer, veering through east, often blows steadily from almost due south; and in the southern part of the China Seas its prevailing direction at that season is from the same quarter: it blows on to the coast between the Gulf of Tonquin and the Strait of Formosa, in precisely the same way that the wind, in the Gulf of Mexico, blows on to the coast of Texas and Louisiana. Of the winds in the interior of China we have no exact knowledge, but at sea they veer through south towards west, and finally near Japan merge in the prevailing westerly winds of the North Pacific.

The South-West Monsoon of the North Indian Ocean is frequently brought forward as a very distinct instance, and most satisfactory proof, of the influence of the rotation of the earth. It is said that the South-East Trade of the South Indian Ocean, crossing the Line, is a volume of air moving from a lower to a higher latitude; that it thus carries with it into those higher latitudes the equatorial velocity, and appears consequently as a westerly wind.* But such a view ignores the fact that, in the Indian Ocean, the air, in June or July, has, at the equator, a very sensible velocity from the east—a mean velocity of, perhaps, not less than ten miles an hour. If that easting is due to the rotation of the earth, it is due to the volume of air having at the equator the velocity it acquired on the parallel of 9° or 10° S.; it is, therefore, this relative velocity of ten miles, this actual velocity of 890 miles an hour, that it carries into north latitude, so that it cannot have any westing at all until it approaches the parallel of 10° N., and then but little; whereas, as a matter of fact, the summer monsoon blows decidedly from the S.W. on the

* Dove: *Op. cit.* p. 65.

coast of Ceylon and in the Gulf of Manaar, between the parallels of 5° and 8° N.; and on the Malabar coast, between 10° and 15° N., is a wind due west. And even if we were to suppose that the air crossing the Line did bring with it the equatorial velocity, this would still be insufficient to account for the westing which the monsoon has in these low latitudes. And an instance of this, even still stronger, is offered by Captain Burton's observations on the top of the Camaroons Mountains, in lat. 4° 30′ N.,* where the strong westerly wind, which was seen driving the clouds high over head, could certainly not owe its westing to the shortening of the degrees of longitude.

Summing up the several steps in the argument, I conclude that the rotation of the earth does not materially affect the direction of equatorial or polar currents of air; 1st, because the friction between the air and earth is so great, that the air almost instantaneously acquires the velocity of the points of the earth to which it is translated; 2nd, because the rotation of the earth would in no way explain the due easterly or westerly direction of currents of air,—a direction that is very common, and in some localities rarely deviated from; and 3rd, because currents of air very frequently, and in some localities very commonly, move from the north-west or south-east in the northern hemisphere, and from the south-west or north-east in the southern hemisphere, directions diametrically opposed to the tendency imparted by the rotatory motion of the earth.

There is another objection which might be made to this theory which we have been considering, not directly referring to the influence of expansion by heat, or of the rotation of the earth, but rather to the general inferences which

* *Ante*, p. 96.

have been founded on their supposed effect. One of these inferences is the existence of the calm belts near the equator and the tropics, in which currents of air ascend or descend. It may readily be granted that calm belts would exist in places where the air did continually ascend or descend in a manner such as has been supposed; but there seems absolutely no reason at all, from evidence of fact, to say that *belts of calm* do exist anywhere on the face of the globe. A belt of calm can only be understood as meaning a zone, extending continuously round the world, between, or approximately between, some specified parallels of latitude; and it is necessarily a series of such belts that is to be inferred from Hadley's theory, or from any of the later modifications of it. Near the tropics, in the Atlantic, whether North or South, there is a strong, steady, and permanent current of air flowing towards the equator down the coast of Africa,—a current of several hundred miles in breadth; and on the western side of each of these basins there is a broad current of air flowing from the equator, more or less marked at sea on the eastern coasts of America, North or South, but more persistent still further to the west, whether in the northern parts of the Gulf of Mexico, in Texas, or Louisiana on the one hand, or on the plains of Paraguay and La Plata on the other; whilst near the equator, although the well-known calms of the Doldrums lend a certain support to the statement, it is found that these rarely extend much to the westward of the meridian of 30° W., beyond which fresh easterly breezes, inclining sometimes to the north, sometimes to the south, will almost invariably be met with.

In the Pacific, there are fresh polar breezes on the west coast of America, in both hemispheres, whether on the coast of California or of Chili, which show no sign whatever of any calm region in the vicinity of the tropic,

or, in the widest sense of the hypothesis, between the latitudes of 25° and 35°; and on the western side of the ocean the absence of any region of calms is equally noticeable. It is across the very parallels where the hypothetical calms of Cancer are said to prevail, that the monsoons of the China Seas blow with their full force, whether in winter or in summer; and on the eastern coast of Australia gales of wind are far more common than calms, and breezes, fresh, though not very persistent in direction, more common than either; whilst, near the equator, a light air from the eastward reaches from a few degrees west of the Gallapagos to the very coast of Borneo. In the South Indian Ocean, the wind blows fresh from the southward all along the coast of Australia, from Cape Leeuwin to the North-West Cape; and at the equator, Captain Maury, himself the most zealous upholder of this opinion, is at considerable pains to show that during the northern summer, the South-East Trade of the South Indian Ocean blows freshly across, and that there is no trace of any calm belt.*

It may be said that the instances I have just mentioned are exceptional, that the winds blow across parallels of latitude on which calms are admittedly not unfrequent, and that these prove the rule. It might as well be said that the Trade winds of the tropical, or the westerly winds of the temperate zones, are exceptional, and blow across meridians of longitude, on which calms are not unfrequent, and that therefore there are strips of calm running from north to south right round the world. And whether the instances given are exceptional or not, they certainly are opposed to the hypothesis that volumes of air in these latitudes are constantly ascending or descending; for there is nothing in the hypothesis to show why there should

* Phys. Geog. of the Sea, § 694.

be, near the tropics, on the eastern or western sides of the great oceanic basins, wide districts where the air does not ascend or descend, or why at the equator it should ascend, and, by ascending, produce calm only in the eastern parts of the Atlantic and Pacific.

There is one more point in connection with this theory to which I would call attention. It is this—that if air enters into the supposed belt of equatorial calms in the manner and with the velocity stated by Captain Maury,* there must be a very sensible ascending current to carry it off. He considers that, from each hemisphere, the air, to the height of 3 miles above the surface of the sea, is pouring with a constant velocity of 20 miles an hour into this *belt of calms*, which is 60, 100, or 300 miles broad. According to this rate of influx, the whole lower part of the air in the belt, to the height of 3 miles, is changed in 1·5, 2·5, or, at most, 7·5 hours; the air, therefore, rises at the rate of 3 miles in 1·5, 2·5, or 7·5 hours, or at the rate of 2, 1·2, or ·4 miles in one hour. Now, a current of air moving with either of the first two of these velocities would be quite perceptible. A wind from one to two miles an hour swells a ship's sails, and gives the ship herself steerage-way. A current ascending with that velocity would carry up with it light objects, such as bits of paper or shavings, and that not in a whirl, but in a gentle, steady manner. It is quite certain that such an effect was never witnessed in a calm near the Line.

A due examination of facts actually observed leads me thus forcibly to the conclusion that there is no continuous and sensible circulation of the atmosphere in vertical planes, such as the Hadley, or the Hadley-Maury, system supposes. The theoretical arguments against such a circulation seem to me to be of the most serious import-

* Phys. Geog. of the Sea, § 356.

ance; but far beyond any such consideration, I place the simple geographical fact, that such a system describes phenomena which do not exist, and misrepresents, or does not account for, phenomena which do. Notwithstanding its wide, its almost universal, acceptance, I venture, therefore, to discard it, and to seek amongst the laws of Nature, especially amongst the laws of the motion of fluids, for some system more exact and more comprehensive.

# CHAPTER III.

## RAIN.

### SECTION I.

#### Evaporation and Condensation.

Water has the property of throwing off from its surface a portion of its volume, in the form of a colourless invisible gas, which is usually spoken of as *aqueous vapour*. The elastic force of this vapour depends exclusively on the temperature of the surface; it is extremely small when the temperature is very low, and rapidly increases as the temperature increases, but for any given temperature it is always the same.

When the surface of the water is pressed on by vapour having the elastic force due to its temperature, it is unable to throw off any more: as, however, aqueous vapour is highly elastic, mixes readily with air, and, being specifically lighter than air, freely disperses into the surrounding space, it seldom retains that force which corresponds to the temperature; and the water continuing to throw off vapour, continues to diminish in volume. This process is called *evaporation*. But when the space above the surface of the water is bounded, the elastic force is not dissipated; the space becomes filled with vapour, the pressure of which on the surface prevents the formation of any more. This peculiar action of aqueous vapour

has never been satisfactorily explained: the pressure of air on the surface of water does not stop evaporation; and into dry air, whether it be at its normal elasticity, or has it reduced by exhaustion, or increased by compression, as can readily be done under the receiver of an air-pump; whether the pressure of the air be equivalent to the weight of a mercurial column of 15, or 30, or 60 inches, evaporation goes freely on; but the pressure of even a small amount of aqueous vapour very sensibly checks evaporation, and that particular amount of pressure which corresponds to the surface temperature—a pressure which cannot be exceeded—stops it altogether. Now this pressure, at low temperatures, is absolutely very small; at freezing point it is only equivalent to ·2 inches of the mercurial column: at 60° F. it is little more than ·5, and at 80° F. is only 1 inch. That this slight pressure of one gas should produce an effect which 50 or 100 times the pressure of another is incapable of doing, is but one of the very many phenomena in chemical science, which we admit as matters of fact, without being able even to guess at the reason of them.

And this, as a matter of fact, is within the scope of every-day experience. Without having perhaps ever thought of it, we all know that a current of air playing over the surface of water makes evaporation go on more quickly; it carries off the vapour as fast as it is formed, not allowing its pressure on the surface to check the formation of more; we all know that it is of little use to hang out washed clothes on a damp still day; the vapour in the air presses on the wet surface of the clothes, and checks, if not altogether hinders, evaporation—that is, drying; and the old master's mate who, as naval tradition tells, remarked, by way of small talk, to his ball-room partner, that it had been a fine day for scrubbing hammocks—although he had probably never heard of natural philosophy—was yet

practically as well acquainted with this fact, as is a dog, who makes a straight cut across a field, with the proposition of Euclid, which demonstrates that any two sides of a triangle are together greater than the third side.

The temperature of water, from the surface of which evaporation is going on, decreases; the water loses heat, and to keep it at a uniform temperature, heat must be supplied to it. This cooling effect of evaporation is well known; many of us have probably often cooled a bottle of wine by wrapping it up in wet flannel and hanging it in a draught; the heat is drawn from the wine to keep up the temperature of the water in the flannel. The danger of sitting in wet clothes is from the same cause; it is not the mere cold of the water that chills, it is the drawing of the warmth from the body by the evaporation. On a larger scale, this chilling is capable of producing very strongly marked climatic results; where water lies freely over the face of a country, its evaporation very notably lowers the general temperature; and the improvement in the modern climate of Europe, as compared with that of former days, would seem to be in a great measure due to the extensive scale in which draining has been carried on for the direct advantage of agriculture; the long severe winters which enabled our grandfathers or great grandfathers to drive waggons, to roast oxen, or to hold picnics on the frozen Thames, have passed away probably for ever, or until the country reverts to its pristine barbarism.

The additional heat which is supplied to water whilst evaporating is expended in converting the water into vapour. It does not raise the temperature of either the water or the vapour; it cannot be detected by the thermometer, and yet, as the volume of water becomes changed into a volume of vapour of the same temperature, this heat which has been supplied must, in some manner, be contained in the vapour; it has therefore been called

*latent heat*, and was till recently supposed to lie mysteriously hidden amongst its particles, ready to be brought to light when it should be reconverted into water. Modern science has explained this mystery: heat and force have been proved to be essentially the same, and the latent heat of vapour, far from being really latent, has been shown to manifest itself as the *elastic force*, the increased potential energy, with which the ultimate particles of the fluid repel each other.

There is then an absolute quantity of heat, much greater than that shown by the thermometer, which is necessary to keep water in the form of vapour, at a certain specified temperature, and when the vapour in any way loses a portion of this heat, it resumes the form of water,—it is said to be *condensed*. In *condensation* a very considerable quantity of the heat which has been acting as the "potential energy" of the particles is set free to manifest itself in other ways. Most people know by painful experience how much more severely steam burns than boiling water, though the temperature of the two, as shown by the thermometer, is the same; the steam coming in contact with the colder skin, is condensed, and the heat thus set free, which is far greater than the heat of boiling water, causes the worst part of the burn. If a quantity of boiling water be poured into a vessel containing cold water, the temperature of the mixture will be somewhere between that of the two waters, and in proportion to the relative volumes in which they are mixed; but it can never reach the temperature of boiling water. If, on the other hand, a jet of steam showing on the thermometer the temperature of boiling water is thrown into cold water, it will very readily raise it to the boiling point; the steam entering into the cold water is condensed, and the liberated heat produces the effect.

And in all cases, where a volume of vapour is chilled,

so that the heat, no longer able to maintain it as vapour, would allow it to resume the form of water, a certain portion of it does become water, and remain water; but another portion, acted on by part of the latent heat set free, is immediately reconverted into vapour, to be again converted back into water if the chilling is continued; whilst the remaining part of this heat is thrown off against neighbouring bodies, or into the surrounding space.

As I have already said, the pressure of air on the surface of water does not materially affect the process of evaporation. Vapour is thrown off into dry air as into vacuum. A limited space is capable of containing a certain quantity of vapour, corresponding to the temperature; and that, whether it is filled with air or not: until the space does contain this quantity, vapour will continue to rise, though more and more slowly as the air above the surface of the water more and more nearly approaches the state of *saturation*. At the same time, however, the space being confined, the elastic force of the mixture is greater than that of the air by the elastic force of the vapour which has been thrown off into it. If, for instance, the elastic force of the air is equivalent to thirty inches of mercury, and that of the aqueous vapour to one inch, the elastic force of the mixture is equivalent to thirty-one inches. In unconfined space such a difference is not to be met with; for as soon as the elastic force of one body of air becomes greater than that of the air adjoining, whether by the admixture of aqueous vapour or otherwise, its volume forcibly enlarges itself; it thrusts itself in amongst the other, decreasing its own elastic force, increasing that of the air into which it enters; there is, in fact, an unceasing endeavour to maintain the equilibrium of elastic forces. In addition to this, aqueous vapour is specifically lighter than air; and air, with which a large quantity of vapour is mixed, is specifically lighter than

air which is comparatively dry; humid air has therefore a continual tendency to rise. Acted on by both these causes, the air over the surface of water is constantly changing, and very rarely reaches the point of saturation.

The aqueous vapour, thown off at a certain temperature, being thus expanded, sensibly loses its elastic force, and assumes the elastic force due to a temperature considerably lower, and will not begin to condense till the air which contains it is cooled down to that lower temperature. The exact temperature at which the vapour begins to condense is called the DEW POINT; and it will readily be seen that the comparison of the DEW POINT with the temperature of the air affords a direct way of measuring the humidity of the air.

The dew point is observed with various instruments known as hygrometers—measures of moisture—or by a pair of wet and dry bulb thermometers; but it may be found with tolerable accuracy by pouring cold water into a tumbler partly filled with water of a temperature nearly equal to that of the surrounding air. The temperature of the water in the tumbler decreases as more of the cold water is added, and at some particular temperature a film of dew *first* forms on the outside of the glass. This particular temperature, carefully measured by the thermometer, is the dew point.

And in free Nature, when the air comes in contact with solid bodies or the surface of the earth, having a temperature below or not greater than the dew point, it deposits moisture on them as DEW; but if a considerable volume of air not in contact with the surface be cooled down to that point, the moisture, on the verge of condensation, or occasionally, even partly condensed, becomes visible as FOG or MIST, and when the temperature sinks decidedly below it, the moisture falls as RAIN.

## SECTION II.

### The Causes and Geographical Distribution of Rain.

The rainfall and the prevalent winds of a country seem to be so closely connected with each other—a change from wet to dry or from dry to wet is so frequently preceded, accompanied, or immediately followed by a change either in the force or in the direction of the wind, a change that in many places lasts during the continuance of the weather which ushered it in—that the nature, cause, and extent of the rain in different parts of the world has necessarily an interest directly belonging to the science of anemology, independent of the very great interest which it derives from the habitudes of the human race, or from the influence which it has on climate and on agriculture.

Many very different theories have at different times been laid down by philosophers of no mean repute, as explaining the causes of rain; but most of these, based upon imperfect experiment or insufficient observation, have not stood the crucial test of experience and careful examination into fact. They can, therefore, now be considered as little more than the footmarks of able men, who wandered astray in their search after truth. I may be permitted, however, to notice one which was pretty generally accepted not so very many years ago; the more because, in pointing out its fallacy, I shall have an opportunity of pointing out a property of fluids, to which I shall have afterwards frequent occasion to refer. The theory propounded by Dr. James Hutton, in the end of the last century, is this:—*When two volumes of air saturated with moisture, at different temperatures, mix together, the temperature of the mixture

* Dissertations on different Subjects in Natural Philosophy, 1792, p. 9.

will be the mean of the two original temperatures, but the *capacity for moisture* of the mixture will be considerably less than the mean of the two original capacities. The mixed volume, being therefore unable to contain all the moisture, will precipitate a portion of it as rain.

Reference to a table * of the elastic force of aqueous vapour at different temperatures will at once show that the law just enunciated is true, so far as the *capacity for moisture* is concerned. The capacity of a volume of air, at the mean temperature of two other volumes, is less than the mean of the two capacities, although, indeed, the difference is slight and quite insufficient to account for the deluging showers which are experienced occasionally even in this country; but as regards the statement that the temperature of the mixture will be the mean of the two original temperatures, there can be now little doubt that it is incorrect. The experiments on which Dr. Hutton relied were made on homogeneous bodies. Later experiments show that heterogeneous bodies do not follow the same rule, and two volumes of air both saturated with aqueous vapour are clearly compound. It is further quite evident that the very first condensation of vapour under such circumstances must, by setting free its latent heat, raise the temperature of the whole mass, and thereby increase its capacity for moisture.

But setting on one side all the experiments which would tend to prove or disprove the truth of the statement, no property of fluids, whether liquid or gaseous, is more certain than this—that two volumes of the same fluid, at different temperatures, or having, from whatever cause, different specific gravities, do not *readily* mix in an intimate manner. This, as a fact, is familiarly known in every kitchen; and the first intelligent cook with whom the reader has an opportunity of talking, will tell him that

* James Glaisher, F.R.S., etc.: Hygrometrical Tables.

if milk or soup cold is added to milk or soup boiling, the two will not mix for some time, even though they are well stirred together. The stirring will divide and subdivide the quantities of each; but after even a considerable interval of time, the spoon will bring out a spoonful perhaps cold, perhaps hot, or possibly with one side hot and one cold, but not a spoonful at a uniform mean temperature. The hot and cold liquids lie touching, but quite distinct from each other, like the fat and lean in a flitch of streaky bacon.

The same effect may be noticed in other and less dense liquids, although not in such a strongly marked manner The public swimming bath on St. George's Pier, Liverpool, is, or was, a few years ago, warmed during the winter by a jet of steam thrown in at one corner. The temperature of the whole volume of water in the bath was undoubtedly considerably raised; but the quarter of the bath near that corner above the opening of the steam-pipe was very much warmer, in fact, disagreeably warmer, than the other parts of it. Another and very striking instance of this is offered by the confluence of the waters of the Rhone and Arve, below Geneva. The Rhone, issuing from the lake, is a pure clear stream; the Arve, fresh from the valleys of the Alps, rolls down a large quantity of mud. Between the waters of the two rivers there is a very noticeable and apparent difference. It is thus seen, at a glance, that when they join they do not mix. For several miles they flow together, side by side, with a sharp line of demarcation between them, the clear water keeping to the right bank, the muddy water to the left.

Nor is this remarkable property peculiar only to liquids. A quantity of hot air charged with colouring matter—smoke—so as to be distinctly visible, may be seen shot up from the nearest chimney into the colder surrounding atmosphere. The hot air evidently does not mingle with

the cold, but drifts away as though it were a body of an altogether different nature, till, as its outside surfaces cool down, they, one by one, fall off from the main body, and hang, as it were, loosely in space, for a few seconds before they lose all distinctive character. I have already spoken of the cold air which comes in underneath a door, and, not mingling with the warm air of the room, forms a cold stratum over the floor. Something of the same kind takes place when a door or window is opened in a hot church, concert-room, or theatre. The cold air as it enters does not diffuse itself over the whole lower part of the building. The general cooling effect from it is very gradual. It keeps together in one mass, and, as such, forces its way often the whole length of the floor, or, perhaps, turned by some obstruction, makes a more or less complete circuit, and any person sitting in the course of the stream, feels the sharp, cold nature of it markedly distinct from that of the warm air of the room.

On a larger scale, this property of fluids is even still more observable in many natural phenomena, which I shall have to notice in due course. The familiar instances I have given here are sufficient to call attention to it, and to show that it alone must necessarily prevent the condensation of vapour according to the law proposed by Dr. Hutton; and if two masses of air of different temperatures and different capacities for moisture will not mix, it is useless for all the purposes of our present inquiry to examine into the temperature of the mixture, or into the extent to which the capacity for moisture changes.

Defining rain to be the free condensation of the aqueous vapour contained in the air, it may be laid down as an axiom that that vapour is, for the most part, thrown off into the air from the surface of the ocean, and carried by the various atmospheric currents to the different localities where it is precipitated. It is unnecessary to enlarge on this prin-

ciple, for, however great may be the evaporation over the face of some countries, as, for instance, in the basin of the Amazon or of the Mississippi, it is clearly insufficient to account for more than a small portion of the enormous volume of water which pours out of those countries into the sea.

It may further be laid down as axiomatic, that when air, which has been borne as wind into any locality, precipitates its moisture, it has been cooled down below its dew point: that the rain will be violent and sudden, not only in proportion to the absolute quantity of vapour in the air, but also in proportion to the suddenness and extent of the chilling to which it is subjected. And, conversely, it may be assumed as self-evident that if the temperature of vapour-bearing air be increased in any way, as it blows over the land—its capacity for moisture being increased, while the quantity of moisture remains the same—no rain can fall from that particular body of air.

From these principles, which, after what has been said on the formation and condensation of aqueous vapour admit of no doubt or dispute, it follows that,

In any country the rain-bearing winds must, as a general rule, blow from the sea:
and also that,

Equatorial winds, winds blowing from lower to higher latitudes, will very frequently be rainy; polar winds, on the other hand, very seldom.

To this law there are, however, some marked exceptions, to illustrate which, it is necessary to examine more particularly into the circumstances which attend the rainy seasons in different localities, as well as the physical nature or geographical position of those countries where the rainfall is remarkable either for its violence, its constancy, or its rarity.

By far the wettest part of the temperate regions of the

Old World is the west coast of Norway. The mean yearly rainfall is there 82·12 inches,* of which 60 per cent. falls in the autumn and winter. Further south, the rainfall in the north of Scotland, in the west of Ireland, and the south-west corner of England, is still very large. In Ireland and Scotland the mean is about 40 inches, and, in particular stations, often reaches to 60 or even to 70 inches. In Cornwall and Devon the rain in winter is almost incessant, and does not very often stop in summer. A boatman at Plymouth once growled to me that "it rained thirteen months out of the year;" and, without exaggeration, the average quantity which falls at Plymouth is 45 inches, and has, in exceptional years, been known to exceed 100.

Eastward from the coast the figures decrease rapidly. Even in the eastern parts of England the rainfall is not more than 25 inches; in Western Germany it is about 20; in Sweden also it is about 20, and does not exceed 15 over a large portion of European Russia. In Siberia it is still less.

On the north-west coast of America we find another instance of a rainfall far beyond what is usual in the temperate zone. At Sitka, the mean of seven years' observation gives it as 89·9, which is nearly equally divided among the four seasons, though the autumnal and winter rains are slightly in excess. According to Mr. Whymper, "it is about the most rainy place in the world; rain ceases only when there is a good prospect of snow." † Lower down the coast, the fall, though not so heavy, still preserves a high

* The rainfall of a district is measured by the depth to which the country would be covered, if it were perfectly level, and none of the rain ran off or evaporated. The estimate of this depth is formed by actually catching and measuring the rain which falls on an area of a few inches by an apparatus called a Rain-gauge.

It may, perhaps, give a better idea of the meaning of inches of rain, to say that one inch is, in round numbers, 100 tons per acre.

† FREDERICK WHYMPER: Travel and Adventure in the Territory of Alaska, p. 75.

average; but the difference in the different seasons is much more marked. On the west coast of Vancouver's Island and of Oregon it is 65 inches, of which nearly half falls in the winter; but at the mouth of the Frazer River it is only 55 inches, and near Fort Vancouver on the Columbia River it is not more than 45 inches. From that, inland, it decreases very quickly, and over a large part of the "Great Basin of the Interior" is estimated at about 5 inches.

It is impossible to examine these two lines of coasts without being struck by the similarity of their position, and the circumstances which attend it. On the north-west of the Old and New Worlds respectively, they are both at the north-eastern corner of a large ocean, over which the wind blows almost constantly from the west. To the northward of 50° or 55° the prevailing direction during the whole year is from the southward of west; but further to the south it is so only during the winter, and through the rest of the year the wind comes very frequently from the northward—is, in fact, a *polar*, not an *equatorial*, current. They are thus both coasts, on the whole extent of which in winter, though only on the more northern parts during the other seasons, the air coming from lower latitudes, and passing over a vast expanse of water, first impinges; and they both have ranges of mountains more or less lofty, running along and nearly parallel to the coast line. In both the great fall of rain is near the shore, and sinks to relative or even absolute insignificance on the other side of the mountains. This is sufficiently evident in the Old World, where the difference between the east and west coasts of Scandinavia—or of Ireland and England—is very great, a difference that is again found on the different sides of the Ural Mountains; but the greater magnitude of the natural features of the country in America brings the fact more prominently forward. The mountain district consists of several ranges, nearly parallel to each other, with no

very wide interval between; and as each in succession from the coast is passed, the country becomes markedly drier, till at last rain ceases altogether to fall, or falls only at rare intervals. In the absence of exact and thoroughly reliable observations, Mr. Greenhow's description of the Oregon territory gives a very clear idea of the successive decrease of the rain. Of the country between the Pacific coast and the westernmost chain of mountains, he says: "The summer is warm and dry, and rain seldom falls between April and November, though, during the remainder of the year, it is violent and almost constant." *

Again, he says of the country to the east of the first or maritime range, extending over about 200 miles to the Blue Mountains:—"The climate of this whole region is more dry than that of the country nearer the Pacific; the days are warm, and the nights cool, but the want of moisture in the air prevents the contrast of temperature from being injurious to health, and this country is represented as being of extraordinary salubrity. The wet season, as in the country nearer to the Pacific, extends from October to April; but the rains are neither frequent nor abundant, and they rarely occur at any other period of the year." And still further east, "the country between the Blue Mountains and the Rocky Mountains appears to be, except in a very few small detached spots, absolutely uninhabitable by those who depend on agriculture for subsistence. It is, in fact, a collection of bare rocky mountain chains, separated by deep gorges, through which flow the streams produced by the melting of the snows on the summits; for in the lower grounds rain seldom falls at any time." †

The geographical similarity between the south-western

* ROBERT GREENHOW: History of Oregon, California, and the other Territories on the North-West Coast of North America, 1844, p. 26.

† *Ibid.* p. 28.

part of South America and each of the localities of which I have just spoken is scarcely less striking than that which they bear to each other. Sweeping over the widest expanse of ocean in the world, the winds which strike on the west coast of Patagonia are for the most part equatorial; but further to the northward, on the coast of Chili, they have that direction only during the winter months, and the period of their duration very sensibly shortens as the latitude diminishes. Immediately behind the coast line rises the mountain chain, lofty and rugged to the southernmost point, although, indeed, its altitude in Patagonia is very inferior to that in the intertropical regions. In fact, comparing the nature of the two countries, and their position to leeward of the North and South Pacific respectively, the only point of difference between the southern part of Alaska and Patagonia which is worthy of notice is, that the ocean to windward of the latter is very considerably the larger. And the nature of the climate is the same, with this difference, that that of Patagonia is decidedly the wetter of the two. In no part whatever of the world is the rainfall so incessant; in no part, remote from the tropics, is it so great as on that coast and in the Fuegian Archipelago.

Eastward of the mountains this striking characteristic of the climate is entirely wanting. Eastern Patagonia is pleasantly dry, and further to the north, where the mountain range is higher, where the mountain district is broader, long and disastrous droughts are far from unfrequent. Admiral Fitzroy says that the want of rain is a serious objection to the country bordering on Bahia Blanco; and that "two or three years sometimes pass without more than a slight shower."* On the Pampas, and the Chaco of La Plata, these droughts produce the most remarkable results with regard to the geographical

* Voyage of the "Beagle," vol. ii. p. 105.

distribution of animals. In the great drought of 1827, 28, and 29, for instance—a drought still spoken of in the country as "Il gran seco"—the destruction of life was enormous, not only amongst the cattle but amongst the wild beasts, of which last, indeed, some species were altogether annihilated.*

An almost similar difference of climate is found in New Zealand. On the west coasts, and especially on the west coast of Middle Island, the rain is nearly unceasing, and the excessive moisture in a comparatively low latitude gives rise to an exuberance of vegetation and a consequent fatness of the soil, which, in the shorthanded state of the colonies, is found to be one of the greatest hindrances to agriculture. High on the mountain range, the vapour is turned into snow instead of rain, and forms itself into the enormous glaciers, which descend from the lofty sides of Mount Cook. On the east coast the climate is much drier; and the plains which lie along the foot of the mountains are described as bearing some resemblance to the prairies of the United States.

These countries then—Norway, Alaska, Patagonia, and New Zealand—distant from each other almost as far as is possible for four countries on the earth to be, have a striking agreement in this: they are situated on the polar side of the temperate zone; they are in the region of westerly winds, and in that part of the region where the westerly winds have a prevailing equatorial direction; they are each to leeward of a very wide expanse of water, have each a chain of mountains immediately behind the coast line; and they have a rainfall, which, differing somewhat amongst themselves, is, in each, very far in excess of what is found in any other part of the temperate zones. The cause of this great rainfall becomes, therefore, an object for consideration; and, whilst we cannot help

* *Ante*, p. 33.—PAGE: La Plata, etc., p. 375.

recognising the effect of the colder climate to which the equatorial winds bring, from over a wide sea, a warmer air charged almost to saturation with moisture, it is impossible to avoid the conclusion that the extraordinary nature of the rainfall is due to the mountain range against which the air, so charged, strikes. To this conclusion we are driven, because we find that in every part of the world wherever a wind from the sea blows directly on—nearly at right angles to—a line of mountains, there is rain, more or less profuse, according to the temperature of the sea from which the air has received its moisture, according to the *absolute* rather than to the *relative* quantity of vapour which the air contains: greater, therefore, in temperate regions when the vapour-bearing winds are equatorial, but great even when they are polar, if only they have passed over a warm sea.

Of this, the mountains of Hindostan furnish the most marked examples. Throughout the whole of that peninsula we find a remarkably large rainfall wherever a mountain range stands as a barrier to the passage of winds from the sea. All down the Malabar coast, where hills of a height of from 5 to 6,000 feet come near the shore, the amount of precipitation during the months of the South-West Monsoon is very great. The mighty Himalaya itself, against parts of which the south-west wind strikes, laden with vapour from the Indian Ocean, throws down enormous quantities of water on to the level plains below; each district being more or less wet according as, from the nature of the country between the mountain and the sea, the wind is less or more interrupted in its passage. The wild country of Sikkim, due north of Calcutta, is one of the wettest, if not the wettest, district of the whole range.* Between it and the sea, the country is almost a dead level, the mountains rising

* HOOKER: Himalayan Journals, vol. ii. p. 388.

abruptly from a plain which has an altitude of only 300 feet; and the southerly wind, charged with tropical moisture, sweeps freely over the land until it meets with the Sikkim Hills. Of these, the outer or southerly line seems to be by far the most wet. A large proportion of the vapour is thrown down from the air at the first check; and further to the northward, and at much greater heights, there is, comparatively speaking, little rain. This is illustrated in a very striking manner by Dr. Hooker's journal of his travels in the higher parts of Sikkim and Nepaul, including the accessible shoulders of Kinchin-junga: during some months spent at a very great elevation—from 8 to 18,000 feet above the level of the sea—he has noted constantly that rain was falling, and yet that the quantity which fell in any specified time was trifling as compared with what fell at Dorjiling, the station on the outer range, which he made his head-quarters. Thus he says:—"During my stay at Lamteng (8,900 feet) the weather was all but uniformly cloudy and misty, with drizzling rain. My rain-gauges showed very little rain compared with what fell at Dorjiling during the same period."* This was in the month of June. At his camp on the Zemu, 12,080 feet, he says:—"Only 3·7 inches of rain fell between the 23rd of June and the 2nd of July, whilst 21 inches fell at Dorjiling and 6·7 inches at Calcutta. During the same period the mean temperature was 48°; extremes 62° and 36·5°; the humidity very nearly at saturation point, the wind southerly, very raw and cold, and drizzling rain constantly fell."† "At Tunga (12,779 feet), from the 23rd to the 30th of July, no day passed without much deposition of moisture, but generally in so light a form that throughout the whole time but one inch was registered in the rain-gauge; during the same time, 4½ inches of rain fell at Dorjiling,‡ and 3½ inches at

* Him. Journ. vol. ii. p. 41. † *Ibid.* vol. ii. p. 59. ‡ *Ibid.* vol. ii. p. 95.

Calcutta." A table of the Dorjiling rainfall during the summer months shows what was precipitated, at an elevation of 7,000 feet, by the southerly wind, on first meeting the high land :—

| | | |
|---|---|---|
| May . . . . | 9·25 | Rainfall in inches. |
| June . . . | 26·96 | |
| July . . . . | 25·34 | |
| August . . . | 29·45 | |
| September . . . | 15·76 | |
| October . . . | 8·66* | |

and this notwithstanding the very heavy rain which falls on all lower Bengal during these months.

But all other rainfalls, however great, are insignificant in comparison with that which is experienced in the mountains of Khasia. This is Dr. Hooker's account of it:— "The climate of Khasia is remarkable for its excessive rainfall. Attention was first drawn to this by Mr. Yule, who stated that in the month of August, 1841, 264 inches fell, or twenty-two feet; and that, during five successive days, thirty inches fell in every twenty-four hours. Dr. Thomson and I also recorded thirty inches in one day and night: and, during the seven months of our stay, upwards of 500 inches fell; so that the total annual fall perhaps greatly exceeded 600 inches, or fifty feet, which has been registered in succeeding years. From April, 1849, to April, 1850, 502 inches fell. This unparalleled amount is attributable to the abruptness of the mountains which face the Bay of Bengal, from which they are separated by 200 miles of Jheels and Sunderbunds."† And a glance at the map will show how peculiarly these mountains stand up, a perfect trap for all the moisture-bearing winds from the south and south-west.

But in Hindostan, whether on the Malabar coast, or in the Himalaya, in Sikkim, in Khasia, or further west, above

* Him. Journ. vol. ii. p. 419. † *Ibid.* vol. ii. p. 282.

the Punjaub, the rainy winds are all equatorial. On the Coromandel coast there is indeed a short rainy season in November, when the North-Easterly Monsoon, blowing over a sea still warm with the heat of summer, strikes, although obliquely, against the Eastern Ghauts; but, during the later months of winter, when the sea has cooled down, there is no rain: and, as compared with the other localities I have mentioned, the rainfall on that coast is trifling; at Madras it is only 45 inches for the whole year, and a considerable proportion even of that falls in June and July. In Abyssinia, on the other hand, a country in which—as the last year's newspapers have told all Englishmen who can read, and many who can't—the mountains are lofty and rugged in the extreme, the winds during the rainy season are from the north and north-west—that is, are polar. These winds come, then, from the Mediterranean. In the Mediterranean, especially in the Levant, where, during the spring, summer, and autumn, the sea is at a high temperature, they gather the moisture which they carry to Africa. They pass over Egypt; but it is notorious that in Egypt, from the earliest dawn of history, there has not been any rain worth mentioning. The land of Egypt, and still more the land further south—the Nubian Desert—is flat, and offers but little obstruction to their passage; it is hot, far hotter than the Mediterranean, and the air has its "capacity" increased, not diminished. Onwards, southwards, the vapour-charged atmosphere blows unceasingly during the whole of the warm months, until, on reaching the highlands of Abyssinia, it precipitates its moisture with a sudden violence and a copiousness which changes each dry bed of shingle into a foaming torrent, and sends down those floods, which every July lay the low land of Egypt under water. "The rainy season," says Sir Samuel Baker, "commences in Abyssinia in the middle of May, but the country being parched by the summer heat, the first rains are absorbed by

the soil, and the torrents do not fill until the middle of June. From June to the middle of September the storms are terrific: every ravine becomes a raging torrent; trees are rooted up by the mountain streams swollen above their banks, and the Atbara becomes a vast river. The Blue Nile and the Atbara, receiving the entire drainage of Abyssinia, at the same time pour their floods into the main Nile in the middle of June. At that season the White Nile is at a considerable level, though not at its highest; and the sudden rush of water, descending from Abyssinia into the main channel, already at a fair level from the White Nile, causes the annual inundation in Lower Egypt."*

Many more instances of this law might be adduced, but those which I have given will probably be deemed sufficient to establish its truth. A mountain range, then, rising in the course of vapour-bearing winds, does cause rain; but in what way? Partly, no doubt, by the cold of its sides, the snow of its summits, contact with which necessarily lessens the temperature of the air, and diminishes its capacity; but by no means entirely, nor even principally. This will be more clear from the consideration that when the wind does not impinge on the line of mountains in a nearly perpendicular direction, the quantity of rain is very markedly less, and diminishes as the angle diminishes, until it ceases altogether, or is confined to the uplands of the mountain district; and this, although the air may be at a high temperature and almost saturated with vapour.

I have already spoken of the profuse rain on the Malabar coast during the period of the southerly monsoon. During the northerly monsoon rain is almost unknown; the line of the Western Ghauts runs as nearly as possible from N.N.W. to S.S.E., the mean direction of the wind during the summer is W.S.W., and during the winter is N.N.W. In both monsoons the wind passes over a wide space of warm

* Albert Nyanza, vol. i. p. 9.

sea, warmer doubtless in the summer; but the southerly monsoon strikes full on the face of the mountains, the northerly glides along nearly parallel to it.

But it is on the west coast of America that we find the clearest illustration of this principle. In Lower Peru rain is absolutely unknown, and yet, winter or summer, the air is so charged with moisture that it hangs over the country as a mist known by the local name of the GARUA. "Theee vapours are not so coarse, low, and gloomy as our fogs, nor separated above, like our summer clouds; but an exhalation between both, being spread all round, as when we say the day is overcast; so that sometimes a fine dew is felt upon the outward garments and discerned by the eye upon the nap of the cloth."* In winter, however, when the northerly or equatorial winds are frequent the fog is much more dense, and forms a dull heavy bank of clouds over the land, and a thick drizzling mist "sufficient to make the streets muddy and one's clothes damp."† The map shows that the line of the Peruvian Mountains is nearly N.N.W. and S.S.E., and the southerly winds of summer, or the occasional northerly winds of winter alike pass along their face, without receiving any direct check. The low land is hot and for the most part arid; the "capacity" of the air as it blows over it is thus, if anything, rather increased in summer, and in winter not sensibly diminished; but in the highlands, and where the wind gets entangled amongst the spurs of the mountain ranges, the precipitation is both heavy and frequent. Further to the north, the same law appears to regulate the interchange of the wet and dry seasons. I have spoken on a previous page‡ of the drenching rains at

* BETAGH: Observations on the Country of Peru; Pinkerton's Coll. vol. xiv. p. 8.

† DARWIN: Journal during voyage of H.M.S. "Beagle," p. 365.

‡ *Ante*, p. 65.

Acapulco and on the coast of Mexico, in summer when the southerly winds prevail. During the rest of the year the climate is lovely; the northerly winds unchecked there, pass on, and striking full on the hills which stretch to the westward and form the promontory of Cape Blanco, throw down their moisture with a copiousness that lays the town of Guayaquil and the adjoining country under water from November to April.

On the coast of Old California, as on the coast of Peru, the winds, whether northerly or southerly, merely skirt the mountain chain, and the burning nature of the soil permits no condensation. At the southern extremity only, where the south-easterly wind of summer strikes on the end of the range near Cape San Lucas, are there occasional showers. Throughout the length of the peninsula, a length of nearly 700 miles, the climate is hot and dry, as that of Arabia; and "many years in succession pass by without the appearance of a single cloud."* In New California, where the west winds of winter prevail from the southward, the quantity of rain is considerable. "Further north the wet season increases in length, and about the Bay of San Francisco the rains are almost constant from November to April, the earth being moistened during the remainder of the year by heavy dews and fogs."†

It appears, then, that the effect of mountains in producing rain is due not so much to the chilling of the air by actual contact, as by the opposition which they offer to the passage of the wind. This may, and undoubtedly does, act in two ways: a great part of the air in motion, impinging on the mountain slope, is reflected upwards; a great part of it is brought to a momentary stand-still before it is pushed out of the way by fresh masses of air pressing on. The latter of these leads us to a consideration of the fact, that

* GREENHOW: Oregon and California, p. 10. † *Ibid.* p. 13.

when air, even if charged with vapour almost or quite to saturation, is in motion, and continues to move without any very sensible check being put on it, it does not precipitate its moisture; but when the motion is stopped, rain follows immediately. The want of rain in the regions of the Trade winds affords the best practical illustration of this: the air of the Trade winds is certainly moist: it passes over a large expanse of water, and it itself, as well as the water it passes over, is at a high temperature, so that the quantity of vapour it takes up must be very great; but whilst it continues in motion as the Trade wind, it precipitates none. The motion of the air in the Trades is singularly equable and uniform; notwithstanding the friction of the surface of the sea, the force which causes the motion is so nicely balanced that there is no interruption. But where this force no longer acts, where the motion ceases, in the Doldrums, the rain descends, not in showers, but in sheets of water: the vapour that has been accumulated during the hundreds of miles of Trade wind is precipitated with a violence which no language can describe more correctly than the homely remark of the sailor, who said, "It's knocked off raining, and 's coming down anyhow."

It may, perhaps, be doubted whether the cause of no rain falling in the Trade wind region is not rather to be found in the fact that the air of the Trade winds is moving from a higher to a lower latitude, from a colder to a warmer locality, and that its capacity for moisture is thus continually on the increase. But that this is not the principal cause seems evident from the peculiar precipitation that takes place as soon as the onward motion of the air ceases. We cannot suppose that the air, which we know to be highly charged with moisture, can carry that moisture through several degrees of latitude, over which the variation in temperature is very trifling, and throw it down in such excessive quan-

tities, in consequence of the chilling effect of a place where the temperature is still very high, if not quite as high as at any point over which the air has already passed; and we are forced to conclude that, in the check which is given to the motion of the air, is to be found the cause of the excessive rainfall of the equatorial calms.

The hydrodynamic principle, on which such a result depends, may be thus stated:—If two fluids, of different specific gravities, mixed, but not in chemical combination, are at rest, they will separate, and the lighter will come to the top; but if they are in motion, they will remain mixed, and will move as one simple fluid. The experience of any dairymaid illustrates the truth of this; cream will not rise on milk which is not kept quite still. We all know, in the same way, that if a cup of tea is left standing for any time, the cream will be found floating on the top; and we can believe that if a pipe carried tea, with cream in it, to any distance, the tea would be drawn off at the far end as satisfactorily mixed as it was at the starting point. Perhaps such an experiment was never tried; but a similar one is performed, on a large scale, every day, in almost every town in England. The sewage, which is carried in pipes for great distances, is discharged from those pipes very thoroughly mixed; but as soon as it is released from the force which drives it out, it begins to throw down the mud—that is to say, a very heavy fluid, which has been till then intimately mixed with the lighter.

A similar thing takes place at the mouth of every large river. The Mississippi, for instance, after it receives the waters of the Missouri, is notably a very muddy stream: the mud which the Missouri, Arkansas, Red River, and a host of other tributaries, pour into it, as well as that which it tears from its own banks in the lower part of its course, rolls down a constituent part of the stream, little of it falling by the way; but as soon as the river

reaches the Gulf, as soon, that is, as a check is put on its onward motion, it begins to throw down the mud, and the bar at its mouth, extending several miles to seaward, is the result. The same is the case with almost every river; there are few, indeed, which have not either a bar, or dangerous mud-banks, at the mouth; and if further illustration were necessary, it would be afforded by the Thames, which is notorious enough for the intricacy of the navigation of the lower part of its channel. In exactly the same way, when air and vapour are intimately mixed, they will continue intimately mixed, as long as the mixture is in motion, as long as a vapour-charged wind is blowing; but when the motion ceases,—when there is a calm,—the air, which is saturated with vapour, and is specifically much lighter than dry air, rises; its temperature is lowered, its capacity for moisture lessened, and the excess is thrown down as rain.

That air in the upper regions of the atmosphere is very much colder than that at the surface of the earth is quite certain. Numerous observations made by travellers in various mountain districts show that the decrease of temperature is about 1° F. for every 350 feet of altitude;* a rude estimate, but one by which the height of hills can sometimes be roughly guessed at, when more correct methods are not available. The property of fluids, however, which, as described above, prevents a volume at one temperature from mixing with a volume at another, shows us that a quantity of air, thrown up into the higher atmospheric

* This is true as a general rule, but there are many very singular exceptions to it. A heated volume of air, thrown by any cause into the upper regions of the atmosphere, may and does hold together, so as to form a hot wind above a colder one; and several hot and cold streaks may exist in alternate strata, one above the other. One instance of this has already been noticed [*ante*, p. 88]; and Mr. Glaisher, in a long-continued series of balloon observations, met with many others still more strongly marked.

strata, is not chilled by its being mixed with the colder air with which it comes in contact. The sudden and violent nature of the precipitation, so often met with, renders it difficult to believe that the chilling which causes it is the result of the radiation into space, although much heat must be lost in that way. The only cause of refrigeration which we can conceive as acting in a sufficiently short space of time is the rising itself. As the volume of air rises, pressure is immediately and continuously taken off it; it expands enormously, and, by the mere dynamical act of expansion, loses heat.

It would lead me far astray from the direct purpose of these pages were I to go at length into illustrations of the remarkable way in which gases are chilled by expansion, or heated by compression. We all know familiarly that the metal receiver of an air-gun becomes sometimes hot to the touch, as it is being filled—that is, by the compression of the air; and, on the other hand, becomes sensibly cold when the air is allowed to rush out of it. The glass receiver of an air-pump filled with moist air, will, if partially exhausted, show clouds and condensed vapour, in consequence of the cold due to the expansion of the air remaining in the receiver; and a still more marked experiment, as performed on a grander scale, with more powerful apparatus, is that in which air was compressed by a column of water 260 feet high, that is, to about one-eighth of its natural volume, and then allowed to escape by opening a stop-cock. The air, as it rushed out, expanded with violence to its original volume, and thus "a degree of cold was produced which not only precipitated the aqueous vapour diffused in the air, but caused it to congeal in a shower of snow, while the pipe from which the air issued became bearded with icicles."* In a manner exactly similar, air rising

* JOHN TYNDALL, F.R.S., etc.: Heat considered as a Mode of Motion, 2nd Edit. § 28, 29.

the upper regions, and having the pressure of the superincumbent atmosphere taken off it, expands and loses heat; at the same time, the mass of ascending air, lifted above the screen of aqueous vapour which, near the surface prevents excessive radiation, throws off its heat into space very rapidly; and the two causes, combining in proportions which it is difficult to determine, are quite sufficient to account for the suddenness with which the vapour is condensed and precipitated.

It seems highly probable that it is by an extension of the principle we have just been considering, that the first land, which a moist wind from the sea meets, so generally causes condensation. As the air blows over land, the friction is greatly increased, so that—as with a railway train when the break is screwed down—the onward motion is lessened, and the vapour is consequently able to ascend. This ascensional tendency is increased by the change of direction given to every particle of air, as it impinges on the various inequalities of the ground, or on the slope of a hill; a change which is given to a larger body of air when the hills rise to any considerable height, and thus intercept more of the onward current, a great portion of which is forced up the slope by the pressure of the air behind, whilst another portion is actually shot upwards by the rebound of its own elasticity.

But notwithstanding this direct, almost exclusive, influence, which we are led to attribute to the ascending current, it is impossible to avoid the conclusion that the surface temperature of the land does, in some way, very materially affect the fall of rain. Air blowing from the sea over a burning sand does not, as a rule, precipitate its moisture, although the inequalities of the ground might be expected to throw considerable volumes of it into the upper atmosphere. Over the great African Desert a vapour-charged wind is constantly blowing from the

Mediterranean: the air which enters at the north, moist almost to saturation, emerges at the west dry to an intense degree; so dry that it shrivels up every substance with which it comes in contact, splits wood-work, and makes horn brittle. And yet, in the interior, rain but seldom falls. Not that it is unknown; there is a short wet season in summer, during which the showers, though occasional, are very heavy; but they do not seem sufficient to account for the remarkable dryness of the desert wind, which blows at times off the west coast. This dryness is probably more apparent than real; air which is nearly saturated at 70° F. is very far from being so when it is heated to 90°, and the greedy way in which it sucks up moisture may be, to a great extent, due merely to its largely increased capacity. But the principal cause of this remarkable dryness is probably to be found in the fact that the aqueous vapour in its passage over this burning land becomes, as it were, superheated; its elasticity becomes enormously increased, it expands to a much greater extent than the air with which it is mixed,* and in that heated and rarefied condition being forced into a higher stratum, is not chilled by the expansion below its dew point, but is borne along towards the sea, and gradually loses this abnormal heat by radiation. On the Californian peninsula, too, the nature of the soil seems to afford the only explanation of the extraordinary dryness; for though, as has been pointed out, the relative bearings of the mountain chain, and the direction of the wind, are sufficient to account for the want of heavy and frequent rains, they can scarcely account for the fact of a country over which a moist equatorial wind often blows, having a climate "dry as that of Arabia."

It is, on the other hand, established almost beyond a doubt, that a luxuriant vegetation, and more especially the

* FAIRBAIRN and TATE: On the Density of Steam at different Temperatures; in Philosophical Transactions, 1860, p. 221.

growth of forest trees does, in some way, cause an increased amount of precipitation. The climate of the eastern side of Chiloe has been in modern times much ameliorated by the clearings which have been made, not only on the island itself, but on the mainland opposite.* In a paper lately read before the Scottish Meteorological Society, it was stated that for some years past the island of Mauritius has been subject to severe droughts. That, so far as can be ascertained, the rainfall from 1861 to 1868 was less than during any similar period since the discovery of the island, a fact which can only be explained as consequent on the cutting down of large forests in the interior, no less than 70,000 acres having been denuded of trees during the ten years ending 1862.† And it is said that of late years rain has occasionally fallen in some parts of Egypt, owing to the growth of trees at the instigation and under the fostering protection of the government.

The climatic effect of trees is undeniable, and, setting aside these extreme examples, is familiar to every one who is at all intimately acquainted with country life; but the cause of their influence is not quite so clear. It cannot be only that the increased friction amongst the branches and foliage allows the ascensional tendency of moist air to develop itself; for the rugged crags of many an arid country are quite capable of doing that. It must be that the vegetable life absorbs into itself a certain portion of the atmospheric heat, and that the ascending air, thus partly cooled in advance, is more readily chilled below the dew point.

To similar causes, though to a far less marked extent, must we attribute the often noticed difference in the rainfall attending a polar and an equatorial wind. In our own country, for instance, the south-west wind brings rain much more frequently than the north-west, though

* Voyage of H.M.S. "Beagle," vol ii. p. 386. † *Scotsman*, July 11, 1868.

this, too, blows over a wide expanse of sea, and is nearly charged with vapour as it reaches our shores; but the absolute quantity which it contains is less, and its "capacity" is increased as it comes over the land, whilst that of the other is diminished. The dew point of the two is different—it is higher for the southerly than for the northerly current, and the air borne along by the latter has to rise considerably higher before it is chilled to the extent of condensation. The seasons on the coast of Oregon seem to be subject to the same rule; the south-west wind of winter causes drenching rains, unknown during the summer when the north-west wind prevails; so that nearly half of a large annual fall is precipitated during the three months of December, January, and February. On the coast of Chili there is the same effect, which we may fairly attribute to the same cause; the more unreservedly, since both in North and South America we find the wet season alternating with the dry, varying in length according to the duration, and, in intensity, according to the predominance of the equatorial or polar winds.

I have dwelt at greater length on this part of my subject because, having once established the facts—

That a wind from the sea, which strikes full on the face of a mountain chain, throws down its moisture with great copiousness; and, deflected into the higher regions of the atmosphere, passes along over the mountain tops, deprived of its vapour and incapable of further precipitation:

That a wind, which strikes obliquely on the line of a mountain range, does not cause profuse rain, but, glancing past the slope, carries its vapour onwards with it:

That, dependent to a great extent on the nature of the soil, a polar wind is for the most part accompanied by dry weather, and an equatorial wind by wet, and by rain more or less heavy:

having established, I say, these as facts, entirely by means of the evidence of what does actually occur in every locality sufficiently well known, supporting it by a more theoretical consideration of the causes and effects of evaporation and condensation, we have certain fixed principles to which we can refer many questions relating to the nature of atmospheric currents; we have, in fact, "put a tally on the wind," which will enable us in a future chapter to trace its course with a degree of certainty which would otherwise be entirely wanting.

# CHAPTER IV.

## THE CURRENTS OF THE OCEAN.

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## SECTION I.

### The Motion of Fluids.

The constant change of the sea level, the rise and fall of the tide twice every day on all coasts open to the ocean, is one of the most familiar of natural phenomena: that this rise and fall is very commonly accompanied by violent rushes of enormous bodies of water, and by strong currents which run for a few hours with great velocity in one direction, and then in the opposite direction with as great a velocity, is also a fact perfectly well-known to everybody. The unknown drift of ships near the land, under the influence of these constantly varying currents, is, every year, the cause of a vast number of wrecks, and is, at all times, the source of painful anxiety to navigators; but, differing in every different locality with every different state of the weather and with every different state of the tide, such drifts can only be thoroughly known to men who make each particular place the subject of careful study, and who learn by actual experience to allow for every change as it occurs. Even the most accurate and minute Sailing Directions are, so far as these Tidal Currents are concerned, frequently in the wrong; for it is not possible to lay down any rules which shall embrace all the changes to which they are subject.

There is no reason to doubt that these tidal currents exert some influence on the open sea, though they do not probably run there with nearly so great a velocity as in the more confined waters near lines of coast. They cannot, however, be detected by any ordinarily available means; for as such a current sets, perhaps, in every direction round the compass in the course of the twelve hours, the resulting effect on a ship's position is little or nothing, and the voyage is neither favoured nor prolonged.

But leaving these alternating tidal currents entirely out of consideration, it has, from a very early period in the history of navigation, been known that the sea is traversed by currents which set continuously in one direction, although it is only recently that any exact knowledge of them has been obtained. Until the improvements in the construction of timekeepers enabled the seaman to determine the longitude and to fix the position of his ship by daily astronomical observations, as long as he was dependent for his daily guidance on the dead reckoning alone, it was impossible for him to tell whether his ship was in a current or not, or to do more than guess, on making a very bad landfall, that the error in his reckoning might be due to a current which in some portion of his voyage had set his ship in some unknown direction. Waifs and strays, cast up by the sea on different lines of coast, were indeed able to point out the country from which they had come, and to hint vaguely at the route along which they had travelled, but could afford no exact information either as to the direction or the duration of their voyage. During the last hundred years, however, since the chronometer has been made an instrument practically useful, our knowledge of the principal currents has been continually on the increase; it is even yet far from exact; but every year, adding the observations of many experienced navi-

gators to those which have been already accumulated, brings us nearer to the truth and renders us more able to form a correct estimate, not only of each particular current, but of the part which it performs in the scheme of oceanic circulation.

In the temperate zone there is in each hemisphere a very decided and clearly marked set to the eastward.* Varying in direction between N.E. and S.E., and in velocity from 10 to 30 miles a-day, it flows in high southern latitudes right round the world, and, on lower parallels, across the Pacific, Atlantic, and South Indian Ocean: in the northern hemisphere it is found across the whole width of the Pacific from Japan or Kamtchatka to the coast of America, and in the Atlantic from Newfoundland to the shores of Europe.

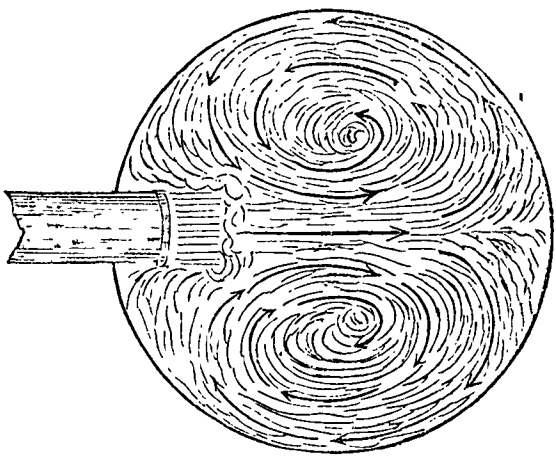
Within the tropics there is, on the contrary, a very persistent westerly set, which, spreading out for many degrees on each side of the equator, is felt both in the Atlantic and Pacific, as also in the South Indian Ocean, almost from coast to coast.

Noticing the remarkable agreement between the direction of these currents and of the winds which predominate in their respective localities, it is impossible to avoid the inference that they are caused by the winds; that the westerly winds outside, or the Trade winds within the tropics, continually rasping over the surface of the sea, with a friction such as I have called attention to above, produces a corresponding motion of the surface water, which in turn drags with it the water below, and that to some considerable depth, though it is reasonable to suppose

* By nautical custom, currents are named by the point of the compass *towards* which they set; winds, by the points *from* which they blow. An *easterly current* is a current running *towards the east;* an *easterly wind* is a wind blowing *from the east.* These opposite methods of naming the currents of air and water may be occasionally perplexing, but any attempt to alter them now would certainly be much more so.

that a current so produced cannot extend more than a few fathoms below the surface.

The quantity of water, however, which is set in motion by these currents is enormous; and though we can conceive that they would flow equably enough under the influence of the same prevalent winds, if lines of coast did not bar their passage; since, as a matter of fact, these coast lines do exist, they produce a very great alteration, not only in the direction, but in the velocity, depth, and general character of the currents which strike against them.



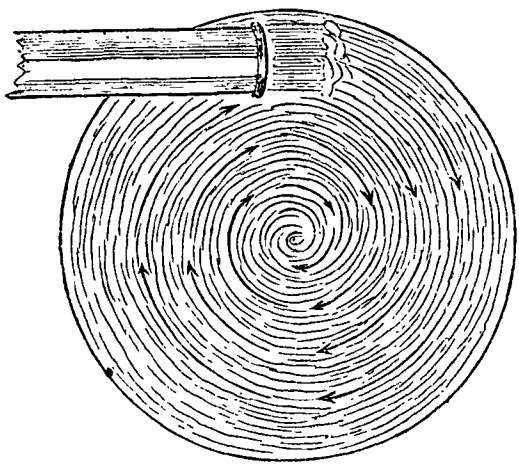
The consideration of these alterations brings us at once to a consideration of the phenomena observed in water, or other fluids in motion; phenomena which, though vague and utterly indeterminate to the mathematician, are, as a branch of experimental science, familiar to us from the days of our childhood, when with a wooden spade we attempted to dam the advancing tide, or screamed with delight as our mimic boats circled round in the eddies of the brook.

If a stream of water strike on any barrier forming a line nearly at right angles to its direction, it will divide itself into two, which will flow, one to the right, the other to the left. This is very easily shown in a common washing-tub. When it is nearly full of water, send a strong stream across it, along one of its diameters; the water, as it strikes the opposite side, will divide, and, unable to escape to the right or left, will flow back, forming two circling currents, such as are shown in the foregoing figure.

The same thing may frequently be seen in a large puddle on a windy day; the wind causes a stream full in the middle, but at the sides the stream runs in the opposite direction, that is, to windward. The wind acting freely would make a stream to leeward over the whole surface; but the water so driven must have an escape. At the sides of the puddle the water is shallower, and the friction, against the bottom and against the surrounding earth, causes it to move with less velocity and to offer the least resistance. An exactly similar thing is to be seen in almost every brook or river. If, in consequence of any obstruction, whether a sudden contraction of the bed, or a weir or dam thrown across, the water is unable to run freely down, it immediately turns aside and flows at right angles to its course, until—checked by the bank—it again turns and flows back in a direction exactly opposite to the flow of the stream. Obstructions, too slight to be readily noticed, are often sufficient to cause this backward flow; for the friction against the banks very sensibly checks the motion of the water in their neighbourhood; and thus, when any obstruction rises in front, the water, pressed on from behind, and forcing itself towards the point of least resistance, will often, near the side of a river, reverse its motion altogether.

That which takes place when the barrier, on which a

stream impinges, is nearly at right angles to its direction, takes place, in a manner even more strongly marked, when the obstruction presents a salient angle. The stream divides to the right and left, and the branches pass on each side of the obstacle. A stick thrust into running water is quite sufficient to show this. The nearest brook, foaming past the boulders that lie in its bed, offers evidence of it as clear and unmistakeable as that of the most elaborate experiment. The piers of bridges, the bows of a ship at anchor in a tideway, the islands which



dot the surface of many a river, are all familiar illustrations. The bifurcation of the Orinoco, where it throws off the Casiquiare to join the Rio Negro and the Amazon, celebrated because unique of its kind, discredited by ancient, marvelled at by modern, geographers, is, so far as the motion of the water is concerned, in no degree more extraordinary than the division of the current which takes place above any of the piers of London-bridge; but the obstacle which divides the current of the Orinoco

happens to be the narrow end of an elevated ridge, which afterwards widens considerably. The distance between the flanking valleys continues to increase, and the branches of the stream, once parted, never meet again.*

When a current strikes on a bounding line, so as to make a very acute angle with it, it does not divide, but glides along the line and adheres closely to it. This may be shown, as before, in a tub, by sending a stream, not along a diameter, but along a short chord, as represented in the figure on page 179. The current that is formed will move round the tub, keeping close to the side the whole way. And this happens not only when the boundary bends or curves across the line of the stream; but when it turns away from its direction, the stream will also turn, very markedly following it round on the salient or convex side of the bend. This, however, it does only in part, and a very large body of the water will rush straight on, clear of the obstruction. All this is to be seen very regularly in the windings of any river. The bank, as it turns back on itself, *appears* to attract the current, and the greater part of the water in the stream sweeps round at an even distance from the point of the bend, whilst that part, which keeps straight on, strikes against the opposite bank nearly at right angles, divides itself, and in part turns back up the river, until, having lost its impetus by collision with the main body of the descending stream above the bend, it is swept aside, once more to pursue its downward course.

It is so much a matter of course for a stream to turn in this way, following the lay of its banks, it is a thing with which we are so thoroughly familiar, that we are apt to overlook the reason of it. Water, the same as any other body, is subject to the laws of motion, and will, when in motion, move in a uniform straight line, if not turned by

* HUMBOLDT: Pers. Nar. vol. v. pp. 448, *et seq.*

the action of some force. In this instance the water does not move in a straight line. There can be no doubt that the force which mainly turns it is the resistance of the opposite bank, against which it would strike if it preserved its original direction. It does not do so ; it turns off before it reaches it, for the bight is filled with water, which is either circling backwards, or is almost still—water that is commonly spoken of as *dead*. This, however, transmits the resistance of the bank, against which it rests, whilst its line offers a much sharper angle to the main current, which, therefore, on striking it, glances downwards with its full velocity, or with a velocity even increased by the narrowing of its bed. But independently of this, there is a portion of the stream which does not appear to feel this resistance at all, and which turns round the salient point under the influence of entirely different forces ; a phenomenon still more manifest as we observe the current clinging round points which jut out into the stream, or round the lower angles of eyots which lie in its course, without either bank or dead water from which it can be reflected. The force that causes this can only be friction.

Whenever the course of a stream is in any way obstructed, the water has a *tendency* to turn back on itself —a tendency which may be observed in other bodies not fluid. If a very thin flexible lath be laid flat on the floor, and, being held by one end, be shoved along,—at the first little inequality which the foremost end comes to, that particular point of the lath stopping, whilst the points in its rear continue to move on, the lath will bend, hogging itself upwards. If, instead of lying flat, it is shoved along on its edge, it will, when it meets such an obstacle, curve to one side ; if it is pushed on against a wall, it will bend till it makes a sufficiently acute angle, and will then glance, so that the foremost end moves in a direction perpendicular to that in which the hinder end, the end to

which the motive power is applied, is moving. And if in so moving it meets another wall, at right angles to the first, as, for instance, in the corner of a room, it will turn on the second wall exactly as it turned on the first, and coming back on its other part will form a ring; and this, merely by steadily shoving from the one end against the first wall.

It is in exactly the same way that a stream of water, which we can conceive as made up of a very great number of threads, or streamlets, turns back on itself. When an obstruction occurs at any point, or when, from any irregularity in the bottom, or otherwise, some part is, for the moment, moving less fast than that immediately above it,—the fine lines of water, in which such a hindrance takes place, being still pushed on by the weight above, curve themselves round towards that point where the resistance is the least. This point of least resistance may be on one side, it may be on the other, or it may be upwards into the air; but, wherever it is, towards it the streamlets will curve. It is in this way that they climb over stones lying in the full stream of a brook: the downward pressure on each side of the stone is so strong, that the bending streaks of water cannot turn against it: they are pinned in by it at the sides; they, therefore, turn upwards, clinging to the stone by reason of their descending velocity, and so, passing over it, fall on the lower side. It is this fall that makes the foam and the fume around such stones; this is the brawling of the brook; but the mere bending of the streamlets is effected without noise. It is, again, in this way that they form the back current which eddies round above any obstruction in their course, and it is still, in this same way, that they appear to cling to the bank, and to turn with it as regularly and evenly as a coach turns a corner in the road.

Compared with the extreme mobility of the particles of water, the most pliant rod which we can procure is rigid

and inflexible; but in exactly the same way as the rod, pushed along a floor, will hog itself up at any trifling obstacle, so, only in a much greater degree, will these fine streaks, which we suppose to form the body of the stream, hog themselves up against all the little inequalities of the bank. They are thus kept constantly pointed towards the bank, driven against the bank, digging into the bank, and that with a force which tears it away bit by bit. It is this that so intensifies the friction of a fluid against a solid; it is this that, retarding the side water of a river, affords to the current a point of least resistance, always ready to hand when any obstruction offers in front; and it is this that, keeping a considerable portion of the stream constantly edging in towards the bank, compels it to follow that bank, however it may turn, and aids the resistance of the opposite bank, transmitted through the *dead water*, to turn the main body of the current into the same course as that part which, nearer to the point, follows it with a closer allegiance.

Amongst all the phenomena which are offered by the motion of running water, there is none more curious than this: that after passing any obstruction in its course, the stream will turn round, and run up towards it, and that often from a very considerable distance. Wherever a point projects into a current, wherever an eyot divides it, there, on the lower side, will be found such a *backwater*. Of the enormous magnitude which such a reverse stream may attain, an idea may be formed, when a man of Captain Speke's experience in river geography was led into supposing that the Albert Nyanza was merely a backwater of the Nile; of its regularity, when Sir Samuel Baker describes how they found the body of a young woman, who was washed away in the flooded Atbara, by floating a piece of wood down the river some days afterwards, confident that it would turn into the same backwater; but a personal experience gives to myself a keener sense of its reality than

either the mistake of Speke, or the correct judgment of Baker.

About four miles above the Dead Sea is a place known to travellers as The Fords of the Jordan. It is not, however, a ford, now; probably never was one, but seems to have received the name on account of a bank of gravel, which stretches the greater part of the way across the river, with a depth of water over it of only a few inches. There is thus a very narrow channel on the further, or Moabitish, side, through which the pent-up water rushes with great force; it forms, in fact, a dangerous rapid, in which, every year, some half-dozen pilgrims are drowned. Here, according to travellers' custom, I bathed; and, having incautiously got into the strength of the rapid, was shot down it with great velocity. I was soon brought to by the branch of a tree, on which I narrowly escaped being snagged; and looking about, with this roaring stream above me, and the river, with high banks densely overgrown with most cruel thorns, below, the prospect was not pleasant. But whilst I had been bathing above the rapid, others of my party had been bathing below, and a friendly voice hailed me to let go and edge across the stream. The snag was 20 or 30 yards below the bank that caused this rush of water; after I let go, I was carried certainly not less than that much further; but as I neared the Israelitish side, I was taken by the backwater,—which thus, in a small river like the Jordan, must have reached at least 60 yards down,—and carried up by a gentle sleeping current, so that I landed without difficulty on the lower side of the shingly barrier.

The cause of this phenomenon, differing from those of which I have already spoken, is to be found, not in the friction of the water against the bank, but in the friction of the moving water against the water immediately below the obstruction, which, being relieved from the pressure of

the water above, is in a state of comparative rest. Against the edge of this body of still water, as against a bank, the stream grinds with the intense friction which I have just described; the result is that the edge is continually torn away: a friction that can dig out great masses of earth and even stone, may readily be supposed capable of rasping off large volumes of a yielding fluid. Into the void thus formed, the nearest available water flows; it cannot come from above, for the barrier shuts off all supply; it comes, therefore, from the still water nearer the sheltered bank and from below. This is again, and continually, torn off and carried down with the stream; and its room is again, and continually, occupied by the still water below. An upward current is thus formed, in a manner which almost exactly resembles the action of the Odorator.*

When a ship is at anchor in a current, whether in a tideway, as at Spithead, or in the stream of a river, as in the Tagus, there is a perceptible backwater of this nature immediately under her stern, in which dirt thrown overboard often hangs for hours; but when a ship is under way, the indraught which follows in her wake, although the same in appearance, is not caused in exactly the same manner. It is due rather to the water astern of the ship rushing forward to fill up the space which the ship, in her onward motion, is each moment leaving empty. This may be shown, in a relatively magnified form, by forcing along, in a direction at right angles to its plane, a flat board, or broad paddle, held vertically in the water; while it carries the water before it on one side, it leaves on the other a deep hole, which is instantaneously filled from behind by water, which thus becomes a following current. The shape of the after-part of a ship diminishes this indraught, and in a ship with a fine run it is very slight indeed; but in ships of clumsier build, it is no difficult matter in smooth water

* *Ante*, p. 130.

to make a bottle, or small piece of wood, follow under the counter for a considerable time.

When the breadth of a stream is in any way lessened, its velocity is, as a rule, increased. I have said that mathematical formulæ become very unsatisfactory when applied to the motion of fluids; for the disturbing forces are so numerous, so complicated, and so irregular, that it is impossible to apply them, in the solution of any problem, with even approximate accuracy. In this property of a stream we can, however, detect a faint trace of that law which teaches us that pressure, which produces motion, is proportional to the product of the mass moved and the acceleration produced. Here, the pressure, produced by the body of water above, remains constant, but the volume of water moved is diminished; in accordance with the dynamical law, then, the velocity should be increased; and we may, therefore, accept this law as explanatory of the increase of velocity when the bed of a stream is contracted, although the irregular transmission of pressure by fluid particles in motion, and the momentarily changing friction, not only between these particles themselves, but also between them and each different particle and projection of the bank, prevents our even expecting to find the increase in strict proportion.

But that the velocity is so increased is a very familiar fact. The sharp propulsion of water through the nozzle of a common squirt, or of a fire-engine, depends entirely on the experimental truth of this rule, and a thousand other instances in common life will readily occur to the reader. On a larger scale it may be noticed in any river when the width between the banks is lessened. The rush of water through the narrow passage at the Fords of the Jordan, already described, is a direct illustration of it; and the similar rush at the Falls of La Guayra, on the Parana, in latitude 24° 4′ 27″ S., offers, according to the account

given by one of the very few civilized men who have seen it, one of the grandest spectacles in this branch of Physical Geography. The river, having at this point a great depth, and a breadth of nearly three miles, is suddenly contracted to a breadth of less than 200 feet. Into this narrow channel the whole volume of water is hurled with the greatest possible fury. The fall in perpendicular height is not more than fifty-five feet, and has a slope making an angle of 50° with the horizon; yet so tremendous is the rush that the neighbouring rocks are shaken by the force of the concussion, the noise can be heard at a distance of six leagues, and the scattered particles of water rise as a mist in columns, which can be seen for many miles.* The effect of Niagara itself, with a sheer vertical fall of three times the height, is scarcely as great; for the volume of the Niagara river is less, and the contraction is not so marked, though even there it seems probable that a great share of the velocity of the stream below the Falls is due to the narrowness of the channel through which it is forced to flow. But the glories of Niagara have been so often dwelt on, and each detail has been so often and so enthusiastically described, that it is unnecessary for me to do more than refer to it as affording, on the grandest scale, illustrations of almost every one of the phenomena of running water, whether in the eddies round the islands above, or in the backwater on the American side below.

It has been conjectured that in the rush through a narrow channel, such as I have been speaking of, the water is banked up to a higher level than it would otherwise have. This seems very probable, and is borne out by the fact, that in the periodic rise of rivers, the rise is greatest in those parts where the river is narrowest, least where it is broadest. The proportion, which certainly

* Don FÉLIX DE AZARA: Voyages dans l'Amérique Méridionale, Paris, 1809, vol. i. p. 71.

exists, in some form, between the pressure, velocity, and the volume of the discharge, may often be preserved by diminishing the volume and increasing the velocity to as small an extent as possible. When the fall of the stream is very rapid, and the velocity great, the intense friction in the confined strait may render any considerable increase of velocity difficult, and demand a greater pressure amongst the particles than does the piling themselves up, so as to increase the depth of the current; an increase which such a current is always striving after, by tearing away and carrying down in its course the earth, stones and rocks, which compose its bottom; but when the fall is gradual, and the stream gentle, there can be no very great rise, or the level would become higher than that of points above it, and the stream would run up. The friction would also, in this case, not offer the same resistance to an increased velocity, and the proportion may be preserved without any very sensible banking up of the water.

To one or other, or, in some cases, to more than one of these elementary principles of Hydrodynamics—principles which I lay down as entirely experimental, the truth of which may be readily tested in a large tub, in a bath, or in the nearest river—I conceive that all the principal phenomena observed in the currents of the ocean, with regard both to their velocity and direction, are to be attributed; I conceive that such currents are, for the most part, mere variations of the westerly and easterly drifts of the water in the tropical and temperate zones; which, occasioned in the first place by the prevailing winds, are in different localities variously acted on and modified by the formation of the land, and the circumstances under which the current impinges on it.* To these principles,

* In order to draw a distinction between the currents formed in the *first* instance by wind, and those *secondary* currents which are the

then, I shall refer in the following account of the known currents, and in the explanation of them which I offer; and, for convenience of reference, briefly enunciate them thus: —

I. When a current impinges on a barrier nearly perpendicular to its direction, it divides into two branches, which run, one to the right, the other to the left.

II. A similar, but more strongly marked, division takes place when the barrier presents a salient angle or curve to the direction of the current.

III. When a current impinges on a barrier at an acute angle, it does not divide, but flows along the barrier, the direction of which it, for the most part, very closely follows.

IV. And generally, without regard to the previous motion, when a current does flow along a barrier, a considerable portion of it clings to the barrier, as though attracted to it, and follows its most minute sinuosities, whether they bend across the direction of the current or away from it.

V. When a current passes any barrier which lies across its course, there is, on the farther or lower side of the barrier, a reverse current, known as a *backwater*, the length and extent of which, depending on the shape and size of the barrier, and the boundaries of the stream, are often very considerable.

VI. When a current, being a certain volume of water in motion, is constrained to move within narrower bounds, the velocity of the current is increased; at the same time

deflections or modifications of them, caused by lines of coast, Major Rennell proposed to call the former DRIFT CURRENTS, the latter STREAMS. The names are appropriate, as referring to the undoubted cause of the DRIFTS, and to the volume, depth, and general velocity of the STREAMS. They have been adopted, both in common usage, and by the Hydrographic Department of the Admiralty; and, in the sense here defined, I shall use them in the following pages.

the depth of the current is frequently increased, sometimes, but by no means always, by banking the water up to a higher level.

## SECTION II.

### The Currents of the North Atlantic.

When the Equatorial Drift of the Atlantic strikes on the coast of South America in the neighbourhood of Cape St. Roque, it divides into two branches, the smaller of which turns southward along the eastern coast of Brazil; the other and more important branch, known as the Cape St. Roque Current, flows along the northern coast in a north-westerly direction until it enters the Caribbean Sea. Formed not only of that part of the Equatorial Current which impinges on Cape St. Roque, but also of the great body of the current which is to the northward, and presses on from the eastward, it is confined within narrower limits, and assumes a velocity far beyond that of the current from which it takes its rise. The Equatorial Drift ranges from 10 to 40 miles a day, its average velocity being between 20 and 30. The Cape St. Roque Current averages from 30 to 50, and occasionally has a velocity of 80 miles in the 24 hours. The pilot charts lately published by the Admiralty set the question of the existence of this current definitely at rest. Its existence, indeed, as a strong and dangerous current, setting ships to leeward of the Cape, and into positions from which they might find it difficult to escape, has long been known; but Captain Maury, on the strength of the reports from a few merchantmen, pronounced it a mere fancy which seldom, if ever, existed.* These reports refer rather to the Equatorial Current to the northward and eastward of Cape St. Roque,

* Maury: Sailing Directions, vol. i. p. 88.

where it has not a great average speed; and the logs and reckonings of merchant ships are not always so correctly kept, as to make it quite certain that a difference of 12 or 20 miles in longitude might not occasionally escape their observation. Horsburgh's notice of it is to the opposite effect. He says that "W.N.W. currents are liable to sweep a ship round Cape St. Roque to the westward," and adds, that "the transports with the ordnance stores on board, for the army of Monte Video, in 1807, by crossing the equator too far to the westward, were carried so far in this direction by the current that they could not get to the southward of Cape St. Augustine, and were twice obliged to stand to the northward into variable winds to regain easting, after having made two fruitless attempts to get into the regular South-East Trade."*

The Amazon and Orinoco both pour their waters into this current, as smaller rivers have previously done into them, but they do not appear to exercise any important influence on it.† The waters of the Amazon at first set to the north-east, but they soon incline to the northward, and falling into the strength of the current, are swept away to the north-west. But the muddy tint and the freshness of the river water are long perceptible to sight and taste; and it is said that ships have watered in the stream far out of sight of land. The effect of the Orinoco is similar, but less marked; though even it can be distinctly traced at a very great distance from the coast. It has been conjectured that the influx of these rivers increases the velocity of the St. Roque Current; but this can scarcely be the case: the Orinoco, indeed, falls into the current at an angle which would cause it to produce quite a contrary effect; and the Amazon, though it strikes it perpendicularly, does not appear to alter its direction,

* East India Dir. vol. i. p. 59.

ADMIRALTY: West India Pilot, 1861, vol. i. p. 14.

without which it cannot change its speed. I would incline rather to attribute the increase, which has been noticed to the north of the mouth of the Amazon, to the lay of the coast; which thence, as far as Cayenne, turns very decidedly to the north, and causes the current to be, in a measure, pent up against it by the westerly set from the more eastern part of the ocean.

Continuing along the coast to the north-west, this CURRENT OF ST. ROQUE flows into the Caribbean Sea, where it loses its distinctive character and velocity. The Equatorial Drift, more westerly in direction, also pours through between the islands which bound that sea on the east, and, uniting with the other, forms a westerly set which sweeps its whole length with a velocity seldom exceeding 30 miles, and presses through the channel between Yucatan and Cuba. Such a westerly current strikes full on the coasts of Belize and Yucatan, bordering on the Gulf of Honduras, and whilst the bulk of it turns to the northward, a small branch runs south and turns to the east, a distinctly-marked eddy as far as Cape Honduras.* The Mosquito coast presents a similar barrier to the passage of a westerly current, and the coast line between the mouths of the rivers Magdalena and Atrato, facing to the west, is itself sufficient to produce a very marked backwater.† The two causes combined do produce a current which turns to the east off Greytown, and runs past Aspinwall with a velocity that occasionally amounts to 70 miles a day.

I have noticed these local deviations from the main current, because, meeting with them at the very outset of this inquiry, they afford such clear and complete illustrations of what I have already pointed out as to the way in which streams make these circling eddies; but it would lead me far beyond what my limits allow were I to attempt to describe all such at equal length. That is the

* West India Pilot, vol. i. p. 18. † *Ante*, p. 189, i. v.

province rather of local Sailing Directions or Coast Pilots; and to these special authorities I must, throughout, refer those who wish to follow out this branch of the subject in greater detail.

The westerly current from the Caribbean Sea, concentrated between the mainland and the island of Cuba, and forcing itself through the narrow channel between Cape Catoche and Cape St. Antonio, has its velocity greatly increased, and runs into the Gulf of Mexico at a rate varying from 30 to 60 miles a day. Here it divides: a certain portion of it hugs the Cuban shore, and turns to the north-east, with a diminished speed of from 14 to 30 miles; whilst by far the larger portion, keeping close to the left shore, sweeps round the Gulf, following its coast-line with the regularity of a stream of water shot into a tub, as shown in the figure on page 179. Past Vera Cruz, past the mouth of the Rio Grande, along the coast of Louisiana, it runs, a broad, deep stream, of no very great velocity,—seldom, indeed, exceeding 30 miles a day. As it approaches Cuba from the north-west, it meets and joins again with the branch which separated from it round Cape St. Antonio, and the united stream attempts an easterly course; but it is met by the Equatorial Current which is pressing towards the west along the north coast of Cuba, and through the Bahamas: it is thus turned to the north; and the whole body of water, formed by the coalition of these three currents—that from the Gulf, that from the north-west coast of Cuba, and that from the Bahama Channel—rushes with great force and velocity through the Straits of Florida, under the distinctive name of THE GULF STREAM.

The high temperature of the water composing this stream—a temperature due not only to the intertropical region from which it takes its origin, but more especially to the Gulf of Mexico, a large, land-locked sea, where the

water is heated to a degree scarcely equalled in any other part of the world,—and the extreme saltness due to the evaporation to which, at such a temperature, it has been subjected, combine to give the stream a character remarkably distinct from that of the water through which it passes. I have shown above * that fluids of the same nature, but of different specific gravities, do not readily mix; and more opposite conditions, of the same fluid, could scarcely occur in Nature than are found in the extremely hot and salt waters of the Gulf Stream, and the comparatively cold and fresh waters of the temperate zone of the Atlantic Ocean, into which they are poured. Accordingly, they do not mix. The great velocity with which the stream rushes through the Straits of Bemini, in the Florida Channel—a velocity varying from 80 to 120 miles a day—carries its waters to the northward in one unbroken volume, easily distinguished from the surrounding ocean by the difference of temperature, and by the deep blue colour imparted by the relatively large quantity of salt which they hold in solution. † Its course can thus be

* *Ante*, pp. 149, *et seq.*

† This is the generally received opinion regarding the blue colour of sea water; and it is quite certain that in the Mediterranean, and within the tropics—more especially in the Indian Ocean—the water is of a blue far deeper than in colder seas, and that it is also much salter. Professor Tyndall thinks that the colour may be caused by infinitesimal particles of matter floating in the water, which reflect short waves of light more copiously than long ones, blue waves more copiously than red: that the deep blue for which the Lake of Geneva is so celebrated may be due to the finest particles of the glacial detritus, which is brought down in great quantities by the Rhone, remaining suspended in the waters of the lake [Glaciers of the Alps, pp. 259, 261]; and that even the blue of the sky "is, or may be, produced by particles suspended in the air, which are not only invisible to the naked eye, but irreducible by the highest powers of the microscope."—[Letter in the *Pall Mall Gazette*, Jan. 27, 1870]. The question is not, perhaps, conclusively settled; but it is sufficient for our purpose here to call attention to the fact that, in the deep sea, the intensity of the blue, and the saltness of the water increase together.

traced without difficulty. The line of separation is so clearly marked that it can be seen from the masthead of a ship at some distance, and the difference of temperature is so sudden, more especially on the west, that the Americans have given the bounding line on that side the name of THE COLD WALL. The United States' Coast Survey shows that this Cold Wall follows a line of soundings nearly parallel to the coast, where the sea suddenly deepens,—as, for instance, off Charleston, where, at a distance of between 60 and 70 miles from the shore, the bottom, which has shelved to 100 fathoms, takes an almost vertical plunge to 700.* It thus approximately follows the line of the American coast, diverging more from it as it proceeds northwards.

From Cape Florida to Mosquito Inlet, through 3¼ degrees of latitude, its course is about N.½ W.

From Mosquito Inlet to Cape Hatteras, through 5 degrees of latitude, its course is N.E.

Off Cape Hatteras it turns to the northward, but shortly after turns again to N.E., and near the parallel of 40° N. turns still more decidedly to the east, its velocity being diminished to between 30 and 40 miles a day.

A singular instance of the visible distinctness of the line of the Cold Wall, and of the advantage which a ship, in a very critical position, derived from it, is mentioned by the captain of a blockade runner during the late war in America. The steamer had left Wilmington during the night, and favoured by thick, hazy weather. About half-past eight in the morning the fog lifted, and discovered her to a large paddle-wheel cruiser not more than six miles astern. In the words of the narrator,—

"The moment she saw us she gave chase. After running for a quarter of an hour it was evident that, with our

* Report of the U.S. Coast Survey, 1860, p. 172; and sketch 19, diagr. 9.

heavy cargo on board, the cruiser had the legs of us; and, as there was a long day before us for the chase, things looked badly. We moved some cotton aft to immerse our screws well; but still the cruiser was steadily decreasing her distance from us, when an incident of a very curious nature favoured us for a time.

"It is mentioned in the Book of Sailing Directions, that the course of the Gulf Stream (in the vicinity of which we knew we were) is, in calm weather and smooth water, plainly marked out by a ripple on its inner and outer edges. We clearly saw, about a mile ahead of us, a remarkable ripple, which we rightly, as it turned out, conjectured was that referred to in the book. As soon as we had crossed it, we steered the usual course of the current of the Gulf Stream, that here ran from two to three miles an hour. Seeing us alter our course, the cruiser did the same; but she had not crossed the ripple on the edge of the stream, and the course she was now steering tended to keep her for some time from doing so. The result soon made it evident that the observations in the book were correct, for until she too crossed the ripple into the stream, we dropped her rapidly astern, whereby we increased our distance to at least seven miles." *

On the east, the line of separation is not so strongly marked throughout this great distance. Unconfined by a coast, or a line of soundings, the waters of the stream spread out with a diminished velocity. By the time they reach the parallel of 35°, the sharp blue line is no longer distinguishable, and at the parallel of 40°, the stream becomes a constituent part of the easterly set, to which it imparts a velocity, depth, and regularity of flow far beyond what is due to the uncertain action of the prevailing westerly winds, and a temperature much higher than would otherwise be found in the northern latitudes of the

* Captain A. ROBERTS: Never Caught, 1867, p. 33, etc.

temperate zone. It thus forms an essential part of, and gives many distinguishing features to, the easterly current, to which, by the common consent of navigators and geographers, it transfers its name.

Impelled, to a certain extent, no doubt, by the direction of the prevailing winds, but for the most part in accordance with the principle I have already laid down, the Gulf Stream divides on approaching the shores of Europe, one branch running in a north-easterly, the other in a south-easterly direction. The north-easterly branch runs up the west coast of Ireland, Scotland, and Norway, carrying with it the high temperature which, from its origin in the Straits of Florida, is the leading characteristic of the Gulf Stream; it turns round the North Cape, and searching into the Fjords in that high latitude, gives them the advantage of an open winter, when the harbours of other countries far to the south are each season closed with ice. Beyond the North Cape its course has not been traced; by the time it reaches that distant headland it has become extremely feeble, and it seems probable that it dies out in the Polar Sea, to the west of Nova Zembla; for though it is occasionally felt as far as Spitzbergen, causing an unusually mild season, such an instance is exceptional, and does not exercise any permanent influence on the climate of that frost-bound island.

It has, indeed, been maintained by some writers that the waters of this stream, penetrating to the extreme north, cause an open sea in the immediate neighbourhood of the Pole.* Such an opinion is entirely speculative; and knowing, as we do, from positive and well-tested evidence, that the Kara Sea, to the east of Nova Zembla, is always impassable,† that northwards, east of Spitzbergen, ships have rarely been able to penetrate further than the 80th parallel,

* MAURY: Sailing Directions, vol. i. p. 258.

† Sir JOHN RICHARDSON: The Polar Regions, pp. 63, 130.

and that, this very last summer, (1869), the private expedition of Mr. Lamont * was completely driven back by the dense pack-ice in that latitude, we cannot allow that the Gulf Stream carries its warmth to the extreme north on the surface; nor can we admit that its water, barely above freezing point off the North Cape, can sink by reason of its great saltness, and rise to the top again, still warm, seven or eight degrees nearer the pole. If its saltness renders it heavier than the rest of the water on the parallel of 78° or 80°, it renders it also heavier than the water at the pole itself.

The influence of the Gulf Stream on the climate of Europe, and, in an especial degree, of our own country is, however, very great. The west winds which strike on our coasts have gathered, from this enormous body of tropical water, warmth and moisture, which they freely distribute along the western shores: it is this that so softens the climate of England; that enables the gardeners of the Scilly Isles, and of Cornwall, to supply our markets with the fruits and vegetables of southern seasons; that covers the cottages in Queenstown or in Rothesay with their magnificent fuchsias; and that, in the same latitude as the ice-bound coasts of Newfoundland or Labrador, renders Ireland emphatically "The Green Island," where frost and snow are almost unknown.

On this account the GULF STREAM has to us a peculiar interest, independent of that which a current of such magnitude and velocity has to the whole maritime world; and has long afforded a field for the speculations of those who have thought that *guessing* rather than *observing* was the correct method of arriving at the solution of a problem in natural science. It was thus, for some time, maintained that the stream was due to the influx of the Mississippi, in ignorance or forgetfulness of the very obvious facts that the

* The Author of "Seasons with the Sea Horses."

waters of the Mississippi would be just as likely to escape to the south of Cuba as to the north; that the stream through the Florida Channel is intensely *salt*, that of the Mississippi *fresh;* and that the Gulf Stream discharges as much water through the Straits of Bemini in one day, as the Mississippi pours into the Gulf of Mexico in three years.

With more plausibility was it held by others that the Trade winds sweeping the surface of the sea before them, piled it up in the Gulf of Mexico, forming what in practical hydraulics is called a "head," the pressure of which drove the water through the narrow Straits. This theory, first proposed by the celebrated Franklin, and strongly supported by Major Rennell, is as near the correct explanation of the phenomenon as could be arrived at without a more strict examination into matters of fact than had then been made, or than was perhaps then possible. Unfortunately, it was accepted as the basis of the theory that there must be a "head" in the Gulf of Mexico; so that when the progress of engineering in the United States carried a series of levels from the mouth of the Hudson to the mouth of the Mississippi, and showed that there was no sensible difference in the sea level of the two stations,* it was at once taken for granted that the theory was refuted; neglecting the fact, so familiar to all engineers, that a "head" is only one way of producing a pressure to generate motion. I have shown above, that when a sluggish current escapes through a passage which is not extremely narrow, water is not piled up to any extent worth speaking of; and it admits of proof, as nearly exact as the necessarily inexact data allow, that the quantity of water which enters the Gulf of Mexico, from the Equatorial Current, is equal to that which is discharged through the Straits of Bemini.

* ELLET: Phys. Geog. of Miss. Valley, p. 11. in Smithsonian Cont. to Knowledge. vol. ii.

This has, I know, been doubted, and some very curious—not to say absurd—guesses have been made, as to the source of the water supply.

In plain figures the question appears thus: assuming the breadth of the stream in the narrows to be 30 miles, its depth 300 fathoms, and its velocity 100 miles a day, the daily discharge is—

$$30 \times 100 \times \cdot 3, \text{ or } 900 \text{ cubic miles.}$$

This undoubtedly errs in excess; the assumed breadth of the narrows is approximately correct; the depth of the channel at this point is 325 fathoms,* but the assumed mean velocity, 100 miles, is the mean velocity of the surface centre, and is certainly far beyond that of the whole body of moving water. It is probable that 50 miles a day would be a much more correct estimate of the mean; but taking the figures as they have been assumed, it follows that the daily discharge through the Straits of Bemini is not greater than 900 cubic miles.

The breadth of the Equatorial Current, from Cape St. Roque to the parallel of the Bahama Channel may be taken as 27 degrees, or 1,620 miles; and its mean velocity, in the open Atlantic, is about 20 miles a day; if we assume its depth as 30 fathoms, we have, as the volume of water which each day passes the meridian of Cape St. Roque—

$$1620 \times 20 \times \cdot 03, \text{ or } 972 \text{ cubic miles.}$$

The same difficulty arises here with regard to the velocity; increased, in this instance, by our almost utter ignorance of the depth of the current. The velocity which I have assumed is, however, the actual mean of the surface, and as 30 fathoms is probably less than the full depth, the error of excess is not, I believe, so great in this last estimate as in the former; and whatever the exact values may be, since the available supply from the Equatorial Current is clearly

* United States Coast Survey for 1860, p. 176.

greater than the discharge through the Straits of Bemini, the comparison is a satisfactory proof that we need not look for any of the mysterious sources which have been suggested. The only one of these suggestions which deserves our notice, is that adopted by Captain Maury, a consideration of which involves a consideration of his theory of the Gulf Stream—a theory which he has supported by the whole weight of his genius, by the whole force of his poetic fervour and impassioned language, but not by the detailed proof and carefully-sifted evidence which exact science demands.

According to this theory the currents of the ocean are mainly caused by differences of temperature in the waters of different latitudes; hotter water, being lighter than the colder, is ceaselessly overflowing it, forming a current on the surface from the equator to the poles; the colder and heavier water forming as constant an under-current from the poles towards the equator. Captain Maury illustrates this view by the extreme and hypothetical case of all the water within the tropics, to the depth of one hundred fathoms, suddenly becoming oil—"A general system of currents and counter-currents is immediately commenced; the oil, in an unbroken sheet on the surface, running toward the poles, and the water, in an under-current, towards the equator."* There can be little doubt that such a motion would result from such a state of things; the oil, or lighter fluid, would, in *an unbroken sheet*, flow polewards over the other, and in the North Atlantic there would be an uninterrupted set towards the Arctic Sea. There is not such a set; the only northerly current in the North Atlantic is the Gulf Stream, which, as it leaves the tropics, is just 32 miles broad. Across the rest of the ocean, from the tropic to the parallel of 40°, there is absolutely no trace whatever of any northerly current; over a large portion of

* Sailing Directions, vol. i. p. 93.

this area there is no current at all; over another large portion the current is southerly; but nowhere is it northerly. It will be seen, further on, that in none of the great oceans is there any prevalence of currents towards the poles, running out of the tropical region; a fact directly opposed to the result foreshadowed by the illustration of the oil and water. But, in truth, the assumption, that the intertropical water is specifically lighter than the water of the polar or temperate zone, is not correct. Whilst heat, by expansion, tends to make sea-water lighter, by evaporation it tends to make it salter, and therefore heavier, and many observations seem to show that in the ocean, the water on or near the parallels of 17° has the greatest specific gravity.* Since, then, the tropical water is not lighter than that of the temperate or polar zones, there is no reason, depending on the difference of specific gravities, why a surface current should flow from the equator; and the theory, which has explained the existence of the Gulf Stream, or any other current, by such a supposed difference, falls to the ground.

But when such a theory is held, and when, misguided by it, a very general drift of surface water towards the poles—a thing not only unsupported by, but entirely contrary to all evidence—is presupposed, it becomes necessary to imagine a supply for the currents constantly setting from the equator. On this basis, a system of large and strong under-currents has been founded, and the water described as setting into the Polar Sea on the surface has been supposed to return to the tropics underneath it, and in an especial degree by a cold current underlying the warm Gulf Stream.

In support of this view, great stress has been laid on the southerly course of icebergs, which are occasionally found in the Gulf Stream, rapidly melting well to the south-

* MAURY: Sailing Directions, vol. i. p. 23. The differences of specific gravity are, however, everywhere extremely small.

ward of the northern margin of the warm water. It is argued that, to get into such a position, they must have been acted on by a strong southerly current underrunning the easterly current on the surface. In the absence of any observations more exact, I would incline rather to the opinion that the iceberg, by reason of its bulk and weight, acquires, whilst in the full set of the southerly current further north, a *momentum* which carries it on when that current has ceased, in exactly the same manner that a ship will go on for a very considerable distance after she has shortened sail, or stopped the engines;—it, in fact, "holds its way." At the same time, it does not seem impossible, or even improbable, that at the meeting of the two currents, the colder one does force itself underneath the warmer, and also "hold its way" for some comparatively short distance; but what I mean is, that no observations have been made with exactness sufficient to establish the existence of such a southerly under-set, and that this occasional drift of icebergs does not necessarily do so.

The soundings and observations which have now, for so many years, been carried on in the Gulf Stream, by the United States' Coast Survey, show that the water near the bottom is cold; and that wherever the bottom rises, there is a corresponding rise in the level of the cold water, which affects the temperature of the stream throughout its whole depth, even to the surface. Running along the coast, at different distances, but nearly parallel to it, are ranges of submarine hills, the culminating lines of which, so far as the observations extend, correspond exactly with the axes or centre lines of cold streaks which run longitudinally along the surface of the Gulf Stream;* and a similar rise in the bottom, a similar approach of cold water to the surface, runs transversely across the Straits of Bemini.†

The low temperature which is found beneath the very

* Report of the Survey for 1860, p. 171. † *Ibid.* 176.

warm waters of the Gulf Stream has been supposed to be the effect of an under-current from the Polar Sea; but in the absence of any direct evidence of a southerly motion of this cold water, it seems more probable that the cold is due to the great depth, to the impermeability of water by the sun's rays, to the dispersion of the heat which such water as is driven to the bottom carries along with it, and, to a very great extent, to the continual but imperceptible interchange which goes on between the waters of polar and tropical seas. I have, on a former page, pointed out the extremely gentle and insensible nature of the circulation which goes on in the air of a large stove-heated room; and though, in the wide ocean, the differences of temperature and expansion are much less, whilst the distances are much greater, not only analogy, but the marked distinction between the very low temperatures at great depths in the Atlantic, and the comparatively high temperatures at similar depths in the same or even higher latitudes in the Mediterranean,* seem to render it certain that, however slowly, the waters from the Arctic do creep down towards the equator.

In the Straits of Bemini the channel is 325 fathoms deep, and the observed temperature at the bottom is 40°; off Havannah, at the depth of 600 fathoms it is only 35°.† This temperature of 35° cannot be carried there by the supposed southerly under-current,—for the lowest stratum in the narrows, some miles to the northward, is 5° warmer, —and must be due, in part at least, to the greatly-increased depth. Still, as compared with other observations, a temperature of 40° is lower than what is usually

* M. le Contre-Amiral COUPVENT DES BOIS: Sur les Températures sous-marines; Comptes Rendus, vol. lxi. p. 678.—Captain T. A. B. SPRATT: Travels and Researches in Crete, vol. ii. p. 341.—See also the Report of the Paper read by Dr. Carpenter before the Royal Society, in the *Times* of Nov. 23, 1869.

† Rep. of the U.S. Coast Survey, 1860, p. 172.

met with, in that part of the sea, at the depth of 300 fathoms. Of the actual depth of the Gulf Stream we have no certain knowledge; but whatever it is, we may reasonably suppose that the pressure of the great volume of moving water on the bed of cold water below—water which is coldest in the deepest hollows of the bottom—tears out by the intensity of its friction a certain quantity of this cold water, carries it along with it as the lowest stratum of the stream, and when it has to pass over ridges such as that in the Straits of Bemini, or along ranges such as those which extend from Cape Florida to Cape Hatteras, or even still further to the north, forces it with it up the ascending, and again down the descending slope, and forms those bands or streaks of cold water which effect such a singular reduction of temperature at low depths, and are quite perceptible even at the surface.

The idea of the cold counter-current setting into the Gulf of Mexico has been conceived mainly in order to afford a supply of water to the Gulf Stream: and, as I have shown that such a supply is not wanted, that more water is offered, with considerable pressure, to the Gulf of Mexico, on the east, than is discharged on the north; that the illustration of the oil and the water does not meet the requirements of observation and fact, since there is no general northerly set, and no difference of specific gravity to call for it; and that the deep water to the south of the Bemini ridge is colder than the coldest water which lies on, or passes over, that ridge; finally, since no observations show any trace of the *motion* of such a current, I conclude that there is no sufficient reason for believing in its existence.

To the west of the Gulf Stream, between it and the coast, there is, however, a feeble southerly current which is known as the UNITED STATES COAST CURRENT. Its velocity is small, rarely exceeding 15 miles a day, and it

would probably be known only to the coasting traders and fishermen, were it not for the remarkable contrast which it offers to the Gulf Stream. Its waters are extremely cold; in winter their temperature is commonly thirty, in summer seldom less than fifteen, degrees below that of the neighbouring waters of the Gulf Stream; they are also comparatively fresh, and of a much paler colour. The waters of the two streams have thus no tendency to mix; they flow side by side in opposite directions, forming at their junction the sharp line called the Cold Wall, visible by the sudden change of colour, and often by a faint ripple on the surface; easily tested by the thermometer which changes from 70° or 80° to 50° or 60°, sometimes within a ship's length.

This cold current reaches as far south as Cape Hatteras, against which projection of the land a considerable portion of it would appear to be deflected, turned to the eastward, and carried away to the northward by the overwhelming velocity of the Gulf Stream. The portion that doubles Cape Hatteras is extremely feeble; and though it is traced as far south as Cape Florida, it is frequently reversed, and a northerly set, which sometimes has a considerable velocity, is experienced.* This is probably caused by the friction of the enormous volume of the Gulf Stream, moving with its greatest velocity, which drags its banks of still water along with it; but though it runs in the same direction as the Gulf Stream, it is still separated from it by the same cold wall which extends from Cape Florida to the neighbourhood of New York.

Along this whole distance, but more especially towards the south, there is, however, a peculiarity of the Gulf Stream which might occasionally mislead the observer: the hot surface waters of the stream very frequently run off to either east or west, and, forming an easterly or westerly *surface* current, overlay the cold water. This

* Rep. of the U.S. Coast Survey, 1860, p. 73.

occasional set is due to the curve of the surface of the Gulf Stream, as traced along a transverse section. The surface is not horizontal, but arched. It is impossible to say that this is always the case; the arching is so slight that it can be measured only by its effect in throwing off, to each side, this set of surface water, and the floating bodies which it carries with it; and as great quantities of *drift* are borne along by the stream to the shores of Europe, it would seem probable that the transverse curve of the surface, often convex, is often also concave.

This may be considered as in some measure analogous to the curve shown by the surface of the mercury in a barometer, which is convex when the barometer is rising, concave when it is falling. This is due to the friction against the tube, which retards the motion of the outer particles of mercury, and makes them behind the others in the direction in which they are moving. A somewhat similar thing may be seen in a wine-glass, when the wine, being carefully and steadily poured in, is made to stand, very sensibly arched, some height above the edge of the glass; but a more correct and apt illustration is afforded by the surface of a river, which is convex when the river is rising, concave when it is falling. In the one case, the *drift* leaves the channel, and tends towards the shores; in the other, it keeps from the shores, and seeks the centre of the stream. "The difficulty of keeping the channel on a rising stream is well known to pilots on the Ohio. The water being then highest in the centre, the boat is continually drawn towards the banks; while every raftsman knows that it requires no skill to float down the current when the flood is subsiding. This fact is well expressed in the language of an old flat-boat man, who assured the writer that he had floated twenty-four hours on a falling river without once wetting a sweep."* This is

* ELLET: *Op. cit.* p. 47.

the immediate result of friction against the banks, which, as in the barometer, retards the upward and downward vertical motion of the surface; but as this motion is itself slow, not perhaps exceeding one or two inches in the twenty-four hours, the curvature must be excessively slight, and would escape observation were it not for its influence on the drift.

The cause of this curvature in the surface of the Gulf Stream cannot be considered as certainly determined; but since it bears such a striking resemblance to the curvature found on the surface of rivers, it would seem probable that it is due to a similar agency. The velocity of the stream through the Straits of Bemini varies from 80 to 120 miles a day; and the increasing pressure of an increasing velocity may produce an effect analogous to the rise; the decreasing velocity to the fall of a river's surface. The observations on this point are not, however, sufficiently numerous or accurate to enable us to form a decided opinion.

But whatever may be the cause, it is a well-known fact that the surface is frequently convex; and to this must be attributed the circumstance that *drift* from the West Indian islands, and wreck from the open ocean, is seldom, or never, thrown up on the coast of the United States. The slight, but frequent surface set from the centre is, in that part of the stream, sufficient to prevent its crossing over to the western side. Further north, where the diminished pressure is probably scarcely subject to sensible variation, the curvature ceases, and drift and wreck is thrown indifferently on the coasts of Ireland or Scotland on the east, or of Iceland on the west.

This fact alone is, I think, conclusive against the influence on the Gulf Stream, which Captain Maury attributes to the rotation of the earth. He conceives that the freedom of the American coast from drift is, *in great*

*measure*, due to the rotation of the earth, which, as I have already explained,* tends to turn towards the east a body which is moving from the tropics towards the north. The drift is, therefore, carried away, and kept by this tendency to the eastern margin of the stream—a tendency which affects the whole body of water, and gives it the easterly direction which brings it to the coast of Europe.

I have already dwelt on this point in considering its effect on the motion of air; but as it has been specially insisted on as an agent producing an important change on the Gulf Stream, I will here briefly revert to it.

When the Gulf Stream leaves the Straits of Bemini, its direction is to the west of north, and it preserves that direction for upwards of 200 miles, when it is turned by the land. That this turn is due to the pressure of the coast-line, or rather of the line of soundings, is evident from the closeness with which it follows it, turning to the north as soon as it is clear of Cape Hatteras, turning eastward again with the coast, and being finally and permanently deflected to the east by the banks of Newfoundland.† The drift from the West Indian Islands, which does not cross the stream in low latitudes, where the opposing tendency of the earth's rotation is least, does cross it freely in high latitudes, where such opposing tendency is the greatest, and is stranded in very considerable quantities on the south coast of Iceland, where, "on the beach under Snaefell, trees with their roots, and scraps of bark, logs of mahogany, and seeds which grow in Jamaica at the nearest, roll in the surf."‡

These two constant and well-ascertained facts are clearly in direct opposition to the theory which ascribes such strongly-marked effects to the rotation of the earth.

* *Ante*, p. 107.

† U.S. Coast Survey for 1860, pp. 173, 176.

‡ Frost and Fire, vol. i. p. 434.

There is another of a more experimental character, which Captain Maury and others have adduced as confirming their views. It is said that in north latitude, on railways whose direction is north and south, the trains continually tend to run off the line to the right hand, towards the east if going north, towards the west if going south, and that, consequent on this, the right-hand rail of each pair always wears away much faster than its fellow. The observations, on which this statement has been founded, must have been partial and imperfect. If the deduction from them was correct, the same result must occur on every railway running north and south; and I have the authority of the superintending engineer of the Great Northern Railway to say that it is quite contrary to his experience, and that there is no sensible difference in the wear of the two rails that form one line of way, although the difference in the weight of traffic does make a very decided difference in the wear of the up and down lines.

And from all these instances, as well as from the considerations previously advanced, I believe that I am justified in concluding that the friction of iron against iron, of wood or water against water, and of air against air, earth, or sea, is so great as to counterbalance the tendency which the earth's rotation has to impart an easterly or westerly direction to bodies moving north or south, and that the effects of this clearly existing tendency are practically imperceptible.

The UNITED STATES COAST CURRENT is the direct continuation of the ARCTIC CURRENT, which, flowing out of the Arctic Ocean, between Iceland and Greenland, continues its southerly course round Newfoundland, and so to the American coast.

The researches of the last few years seem to establish the fact that this current is, in the first instance, merely the escape from the Arctic Seas of the water which the

Gulf Stream and the great Siberian rivers are constantly pouring into them. Near Cape Kanin, a sudden and well-distinguished change in the temperature of the sea shows that the Gulf Stream impinges there on a body of cold water from the Kara Sea, and does not pass to the eastward.*

The drift-wood that covers the north-eastern shores of Spitzbergen, is some of that which the Lena and other Siberian rivers carry into the sea every spring. The course of all these rivers is towards the north, and the ice gives way in the southern or upper portion of them, whilst nearer the mouth they are still frozen. The water, swelled by the melting snow from above, unable to find an escape in the channel of the rivers, spreads over the country, which it inundates to a depth of 30, 40, or 50 feet, and carries with it huge masses of ice, which bear down all obstacles, and drag away whole forests at a time. The quantity of this timber, which strews the beaches of Spitzbergen, is a satisfactory proof that, from the mouth of the Lena, westward, the prevailing set of the current is in that direction.†

The Gulf Stream leaves its own mark upon the coast in a similar manner. The bottles used by the fishermen on the coast of Norway, as floats for their nets, have been found in considerable numbers on the north and east coasts of Spitzbergen,‡ and show that the current, deprived of both its strength and its warmth, feebly moves round, deflected possibly from the coasts of Nova Zembla, and borne back by the westerly set from Siberia.

Analysis of the water of the Arctic Current, as it flows

* PAUL GAIMARD, Président de la Commission Scientifique du Nord : Voyages en Scandinavie, etc. : Vol. Astron. et Hydrog. p. 456.

† LAMONT : Seasons with the Sea Horses, pp. 87, *et seq.*

‡ General Sir EDWARD SABINE, in Proceedings of the Royal Society, vol. xiii. p. 29.

between Greenland and Iceland, shows it to contain the average quantity of salt found in water from milder latitudes.* It is very generally assumed that polar water is comparatively fresh; but it may properly be asked, What is polar water? If polar water is defined to be the water of a sea crowded with icebergs, it is fresh; for icebergs, formed on land, as glaciers, by accumulations of snow, very sensibly lessen the proportion of salt in that part of the sea where they float and melt. But salt water, by being frozen and melted, even many times in succession, does not become fresh; and still less does water become fresh by being exposed to cold, without being frozen. The quantity of salt which the water of this current contains has been claimed as a direct proof that it is absolutely the water of the Gulf Stream, circling round, and running out in one uninterrupted flow; it seems highly probable that the Gulf Stream does, to a great extent, circle in this manner; but the mere presence of the salt in the south-going water scarcely gives us any real information as to the time the water itself has been in the polar regions.

The water which flows immediately out of the Arctic is, however, only a portion of that which forms the more southern part of the Arctic Current. It is joined to the south of Greenland by a large and steady, though not rapid, outflow from Baffin's Bay, which comes, in part, from the westward, through Lancaster Sound, or Hudson's Straits; but to a much greater extent from the north, through Kennedy Channel and Smith Sound, and must be considered as another escape of the water pressed into the Arctic by the Gulf Stream. Ships caught in the ice have thus, on several occasions, drifted to the south during the whole winter; and, not to mention other instances, that of the "Fox," in the winter of 1857–8, will probably be familiar to most readers. During 242 days in the packed

* Prof. FORCHHAMMER, in Phil. Trans. 1865, p. 221.

ice of Baffin's Bay and Davis' Straits, she was drifted 1,194 geographical, or 1,385 statute, miles.*

The united current, which meets the Gulf Stream to the south-east of Newfoundland, thus brings down with it water intensely cold, and, more especially in summer, huge icebergs floating on its stream. The air which lies over the Gulf Stream, warm and moist, being constantly swept by varying winds across the cold surface of the Arctic Current, is chilled, and its moisture changed into rain or snow, but more frequently into dense fog, which, often for weeks together, veils the southern coast of Newfoundland. The icebergs, too, in the warm temperature to which they are thus exposed, or drifting into the Gulf Stream itself,† melt away in that neighbourhood, throwing down as they do so vast quantities of mud, earth, sand, and stones, which they have gathered, either as glaciers on shore, or whilst grinding along the bottom of the sea. The capability of ice thus to transport earthy matter is a question which belongs more directly to the science of geology, and, as such, has been followed into the minute details of its mode of action. I allude to it here, because, working through countless ages on a very large scale, it has materially, though it is impossible to say to what extent, altered the contour of the bottom of the ocean, and has formed, or assisted to form, those banks where the sea suddenly shoals from between 2,000 and 3,000 fathoms to 70 or 80, and where the fishermen reap that rich harvest of their toil which supplies all the markets of the civilized world.

I have already said that the Gulf Stream, on approaching the shores of Europe, divides into two, and have traced the northern branch to its end beyond the North Cape.

* Sir L. M'Clintock: Voyage of the "Fox," p. 109.

† See *ante*, p. 202.

The south-eastern or southern branch follows, in the main, the coast line of Portugal and Africa as far as the Gulf of Guinea; but whilst the general course is thus to the south, there are, in particular localities, some remarkable deviations. The first of these occurs where a part of the stream, moving towards the south-east, impinges on the coast of Spain, near Cape Finisterre. It is deflected to the east,* and again to the north on reaching the coast of France, which it closely follows, turning with it to the north-west along the southern shore of Bretagne, till beyond Ushant it is lost in the open ocean. The strength of this current, which, in honour of the distinguished geographer by whom it was first traced, has been called RENNEL'S CURRENT, is, however, very uncertain; and whilst, after a continuance of fine weather, it is scarcely felt even on the coast of Bretagne, on the other hand, when a succession of westerly gales and strong winds in the North Atlantic has rendered the easterly drift coinciding with the Gulf Stream stronger than usual, and has not only thrown it with greater force on the coast near Cape Finisterre or Cape Ortegal, but has confined it in narrower limits in the Bay of Biscay, it reaches far to the north; and, being still kept to the east, increased and strengthened by the influx of the easterly drift, is traced for some distance up the Irish Sea. This uncertainty in its strength, especially in winter, and the confusion which at all times exists in that locality between it and the tidal currents, renders the approach to the Channel dangerous in weather that has not permitted good sights for latitude,† and several disastrous wrecks have occurred on the Welsh

* *Ante*, p. 189, iii.

† It is this peculiar difficulty in approaching the Channel, this danger on coming into "the soundings," that gave rise to the great importance attached by the old navigators to what they called THE THREE L's—Lead, Latitude, and Look-out.

coast, which must be principally attributed to the force of this current.

On the 23rd October, 1707, after hazy weather and a fresh south-westerly gale, Sir Cloudesley Shovel, in the "Association," with several other ships of his fleet, was lost among the Scilly Islands, when, according to the reckoning, he was in the fairway of the Channel. In November, 1758, after some tempestuous weather, the "Belliqueux," a French ship of the line, was captured in the Bristol Channel, on her way from Quebec to Brest; and, in former days, many instances have occurred of the light on Lundy Island being mistaken for that on Ushant.

Further to the south, where the south-easterly stream meets the African coast to the north of Mazagan, a great part of it is deflected to the eastward. The coasts of Spain and Portugal on the left, and of Morocco on the right, converge like the sides of a funnel, which opens through the Straits of Gibraltar. Westward of this the current has a feeble velocity, varying from 5 to 15 miles a day; but so concentrated, its waters—in obedience to the principle enunciated above*—rush through the narrow passage with a velocity that not unfrequently reaches as high as 80 miles. This current, which may be called the GIBRALTAR CURRENT, would appear to traverse the whole north coast of Africa, pent up against it, possibly, by the prevailing northerly winds of the Mediterranean. But though its rush through the Straits resembles, on a smaller scale, that of the Gulf Stream through the Straits of Bemini, its waters have no quality which peculiarly distinguishes them from the waters into which they pour; they therefore mingle freely with them, and retain but a small portion of the velocity with which they enter the Straits. Still, the easterly set, strengthened by the prevalent westerly and north-westerly winds, is perceptible in the southern parts of the sea, and

* *Ante*, p. 189, vi.

makes itself very manifest, far to the east, by the way in which it carries along with it the mud of the Nile. As it reaches the coast of Syria it turns to the northward, throwing down this mud wherever its course is obstructed. It is thus that the dyke, constructed by Alexander the Great, from the mainland to Tyre, then an island off the coast, has caused such a puzzling change. The dyke, no doubt, speedily crumbled away; but its ruins checked the course of the current, and all around them has, during these twenty-three centuries, so silted up, that, even with the lamp of history to enlighten us, it is difficult to believe in the once insular character of that stronghold of ancient commerce.*

The explanation which I have here given of this Gibraltar Current is, however, widely different from that insisted on by Captain Maury,† and some others who have written on the subject. These consider that the evaporation in the Mediterranean, increasing the specific gravity of the water, causes it to sink, and to pass out through the Straits as an under-current, and that the constant surface influx is an effort of the fluid to preserve its level. But if this were the case, the current could not possibly take the course that it does; the water entering through the Straits might, perhaps, spread itself out, fan-like, and flow to the northward in the Sardinian Sea, in the Adriatic, and in the Archipelago, as well as to the eastward into the Levant; or, since the outgoing water would be drawn principally from the southern parts of the sea—which, being the hottest, are the most acted on by evaporation—these being reduced to a lower level might draw water from the more northern parts of the sea, continually lowering, or tending

* The newspaper comments on the prospects of the Suez Canal have lately brought this current very prominently before the public. Its possible effect is very clearly set forth in the *Saturday Review*, Dec. 11th, 1869.

† Phys. Geog. of the Sea, §§ 378, 547.

to lower, their level also. The Levant would certainly draw its supply from the neighbouring Archipelago—not from the distant ocean; and the current, rushing in through the Straits, would, in part at least, follow up the east coast of Spain, past the Balearic Islands, into the Gulfs of Lyons and Genoa. Of such a current there is no trace. In the western part of the sea the currents seem to be variable drifts, alternating with the winds, frequently from the north, when the usual northerly wind prevails; frequently also from the south, when a southerly wind blows strong for a few days. To the eastward, it is the Levant that pours water into the Archipelago, not the Archipelago into the Levant. Near the Greek coast, a feeble continuation of the strong current of fresh water which runs out of the Black Sea, the escape of the many large rivers, of the Danube, Dniester, Dnieper, and Don, is, indeed, felt; but towards the Asiatic side a set constantly runs by Cyprus and along the coast of Karamania to the north and west; "at times, between Rhodes and the mainland, the current is liable to run like a sluice, insomuch that, in a calm, a ship may be carried up to the north by carefully looking out for eddies, and keeping within the islands near and after passing Rhodes."* Such a statement of observed facts is sufficient in itself to overthrow the evaporation theory; but even were it not, there are other considerations which are scarcely less conclusive. The Mediterranean Sea is, as a rule, exceedingly deep, but is divided into two clearly distinct basins by the bank which connects Sicily with Africa. From Tarifa to Tangier there is a line of soundings on which the depth ranges from 150 to 250 fathoms. From Cape Bon to Sicily there is another line, which, throwing up some dangerous shoals, has a depth which probably nowhere exceeds 250 or 300 fathoms.† East and west of this dividing ridge the depths are very great;

* Smyth: Mediterranean, p. 168. † *Ibid.* p. 137.

fifty miles inside the Straits bottom has been found at from 700 to 950 fathoms.* Near the coasts of Corsica or Sardinia the depth is "prodigious." "The barrier at the entrance of the Straits marks the commencement of the western basin, which descends to an abysmal profundity, and extends as far as the central part of this sea, where it flows over another barrier, and again falls into the as yet unfathomed depths of the Levant basin." † These depths are, however, no longer unfathomed. In 1856–7, Captain Spratt, in H. M. S. "Medina," sounding with improved lines and modern appliances, repeatedly found bottom between Malta and Crete at a depth of about 2,000 fathoms; ‡ a depth which, in a sea so confined, may be considered as fairly meriting the title of "an abysmal profundity," vaguely given to it by Admiral Smyth.

If, then, the salt water, rendered salter and heavier by the great evaporation continually going on from the surface of this land-surrounded sea, sank placidly into either of these *holes*, whether the eastern or western basin, there it would stop. Water cannot, by its own unaided weight, press itself over a shoal, which we may estimate as over a height of 1,800 fathoms, or nearly 11,000 feet; the supply to compensate for evaporation would go on from the ocean, and the bottom must necessarily, in the course of time, longer or shorter, salt up. Since no salt is carried off by evaporation, the bottom of the Mediterranean basins would, long ere now, have become one vast plain of salt. It has not done so. The bottom is not a plain, as I have just said; neither is it salt; it consists of earths and minerals, similar to those which form the basis of the neighbouring countries.§ Neither is the water in these basins intensely salt. The water of the whole of the Mediterranean is,

* SMYTH: Mediterranean, p. 128. † *Ibid.* p. 136.

‡ SPRATT: Travels and Researches in Crete, vol. ii. p. 323.

§ SMYTH: Mediterranean, p. 134.

indeed, somewhat salter than the water of the open ocean, having a mean specific gravity of 1·029 as compared with 1·027. But whilst the specific gravity of the water at the surface, near Malta, was found to be 1·029, that at the depth of 800 fathoms was the same; at 1,200 fathoms was 1·0295, and at 2,000 fathoms was only 1·03, an excess so slight as to be scarcely worth taking notice of.*

That salt is continually carried into the Mediterranean by the Gibraltar Current, that the bottom presents no appearance whatever of being salted up, and that the water, even, is but in a very trifling degree salter than that in the Atlantic outside, are facts generally admitted, and which cannot be disputed. To explain what becomes of the salt has been therefore a favourite problem amongst geographers and hydrographers for the last 200 years; the opinion now commonly held being that there must be a return westerly under-current through the Straits of Gibraltar; an opinion which is maintained on strong theoretical grounds, but which has never yet received any conclusive proof from actual observation.

Sir John Herschel—taking the breadth of the Gibraltar Current to be 4 miles, its depth 30 fathoms, and its velocity 2·5 miles an hour—estimates that the quantity of water carried into the Mediterranean in the course of the year is 2,986 cubic miles, or more than 2,000 in excess of what is necessary to supply the loss by evaporation.†

Captain Maury forms a still larger estimate. He supposes a depth of 400 feet, and a breadth of 7 miles with an hourly velocity of 2 miles; from which, as data, he calculates that 88 cubic miles of solid matter were carried into the Mediterranean in 90 days.‡ This would be equivalent to an influx of 8,577—that is, to an excess of about 8,000 cubic miles of water in the whole year.

* SPRATT: *Op. cit.* vol. ii. 346. † Phys. Geog. p. 28.
‡ Phys. Geog. of the Sea, § 378.

Both these authors have, therefore, confidently asserted the existence of a westerly under-current as necessary to carry off this excess of water; and if there were any real grounds for believing in the existence of such an under-current, the solution of the difficulty would be simple. Captain Maury considers it to be the necessary result of the pressure outwards of the dense water at the bottom of the sea, a pressure which, as I have already said, can no more have even a tendency to cause such a motion than the weight and density of a quantity of mercury in a basin can have to force it in under a quantity of water in a contiguous basin. Sir John Herschel would seem rather to consider it as the effect of the pressure brought on the surface by the superabundant influx—by the *tendency* of the easterly current to form "a head" of water in the confined sea.

That such a pressure would be capable of causing such a current can scarcely be doubted, but, in doing so, it would also cause a violent agitation of the water at the bottom of the sea, and an under-current outwards through the whole extent and depth of the Mediterranean, a result which our present observations do not seem to confirm. A rush of water in through the Straits, such as that at which Sir John Herschel has estimated the influx of the Gibraltar Current—to say nothing of the more exaggerated estimate formed by Captain Maury—would stir up the lower depths of the sea, in much the same manner as the dash of water from an ordinary high-pressure tap stirs up the lowest depths of the bucket into which it pours.

Observations on the movement of the water in the lower depths of the sea are unfortunately very rare, and, in most places, are entirely wanting. It happens, however, that one of our most able surveyors has devoted time, trouble, and skill to an investigation of this branch of the Medi-

terranean hydrography, and the fact that the most delicate experiments, even now possible, have failed to detect a trace of any outward or westward movement of the under water, in the middle of the sea, offers a remarkable opposition to Sir John Herschel's assertion that there must be a westward under-current through the Straits of Gibraltar.

The result of Captain Spratt's observations in 1,750 fathoms, about 100 miles N.E. of Malta, amounts to this:

At the surface, an easterly current of ·3 miles an hour;
At a depth of 10 fathoms, the same;
At a depth of 20 fathoms, the same;
At a depth of 40 fathoms, the same;
At a depth of 50 fathoms, current barely perceptible;
At a depth of 100 fathoms, still water;
At lower depths, still water.

This and some other similar series of observations embody all that is really known of the currents below the surface. Counter under-currents were nowhere found, and the inability of Captain Spratt to detect them throws great doubt on the theoretical reasoning which so positively insists on their existence. We are led, therefore, to inquire whether the influx of the Gibraltar Current is as great as it has been estimated, and, in the absence of exact data, to scrutinize those that have been assumed.

It must then be noticed that the current, although very general, is by no means unceasing in its flow. It rushes through the Straits, occasionally, at the rate of 6 or 7 knots, but such a rush seems to be rather a *tidal* current, and is borne back again after a few hours. It is also practically well known that the current is frequently reversed, and, for days together, runs to the west. Instances have occurred of ships being nearly a month trying to get from Cape Trafalgar to Gibraltar, and, though such cases

* SPRATT: *Op. cit.* vol. ii. p 341.

are extremely rare, forced delays of a week are not unfrequent.*

But, besides this occasional reversal of the main current, there is at all times an outward drift on both sides, near the shore. Ships from the Mediterranean, making the Rock a little to the northward, slip quietly round Europa Point into Gibraltar Bay, even against a head wind, and can, in the same way, pass by Tarifa to the west. Even, then, assuming the breadth of the ingoing current to be 4 miles, and its velocity to be 2·5 miles an hour, the outgoing currents at the sides, having an aggregate breadth of perhaps 3 miles, and a velocity of 1 mile, will very considerably reduce the quantity of water which permanently enters the Mediterranean.

With regard to the depth of the current, we are quite in the dark. Sir John Herschel assumes it to be at least 30 fathoms; Captain Maury supposes it to be 70. It seems, however, legitimate to compare this current with the very rapid stream that runs into the Mediterranean from the Black Sea. In the narrowest part of the Dardanelles, Captain Spratt's experiments gave the following results; with which similar observations made in other places, both in the Dardanelles and in the Bosphorus, were in complete accordance:

At the surface the current was 2·25 miles an hour;
At a depth of 3 fathoms it was 1·5 miles;
At a depth of 5 fathoms it was 1·25;
At a depth of 10 fathoms it was ·25;
At a depth of 20 fathoms there was still water; and
At a depth of 40 fathoms, there was also still water.†

The origin of the Gilbraltar Current in the waters of the Gulf Stream and the South-Easterly Drift outside the

* Laurie's Mediterranean Directory, Edited by A. G. Findlay, 1856, pp. 13, 16.

† SPRATT: *Op. cit.* vol. ii. p. 339.

Straits, as well as the still perceptible eastward motion, detected by Captain Spratt to the north-east of Malta, at a depth of 50 fathoms, compels us to believe that the depth of the current, as it enters the Mediterranean, is very much greater than that of this current through the Bosphorus; but we may still fairly use these measurements as evidence that the velocity diminishes very steadily as the depth increases; so that, though there is nothing to prevent our admitting a possible depth of 60 or 70 fathoms, we cannot admit for a current of such a volume a greater average velocity than 1 mile an hour, and may easily believe that even that is excessive. If, then, we allow a depth of 60 fathoms with a mean velocity of 1 mile, and estimate the outgoing currents to have a mean velocity of ·5, for a depth of 20 fathoms, we have, as the quantity of water thus carried into the Mediterranean in the course of the year—

$$24 \times 365 \times (1 \times 4 \times \cdot 06 - \cdot 5 \times 3 \times \cdot 02) \text{ or } 1{,}840 \text{ miles.}$$

This is still, according to Sir John Herschel's estimate, far more than is called for by the excess of evaporation over the river supply; but, in forming these estimates, the bases of the calculation are so extremely vague that no approach to exactness can be expected; and we may consider that the disparity, between the quantity of water which enters from the Atlantic and that which is carried off by evaporation, is not greater than can be counterbalanced by the occasional reversal of the current in a strong outward rush. And since the outgoing water, whether through the main channel in these exceptional instances, or generally in the permanent side-currents, must be supposed to be of a greater density than that of the incoming water, it does not seem improbable that the excess of salt is in that way returned to the Atlantic.

Without actual survey, it is impossible to speak certainly

on this point, to decide as to the *depth* of the entering current, or to say positively that there is not an outgoing under-current through the Straits; but, as no under-current on a large scale has anywhere been really traced by competent observation, and as, in this special instance, notwithstanding the very strong arguments which have been brought forward in support of the theory, the analogy of the current in the Dardanelles seems to show that it is uncalled for, we may fairly incline to the belief that it does not exist.*

But whatever may be the volume of the current which turns to the eastward through the Straits of Gibraltar, it is only a very small portion of the enormous body of water which flows to the southward past the coast of Portugal: the main current continues its course down the coast of Africa, extending to the westward for from three to four hundred miles; and though, beyond a doubt, the southerly deflection of the Gulf Stream, it is also in great part the drift caused by the prevailing winds, which blow very constantly from between N.W. and N.E. From the coast along which it flows, it is commonly called the

* I have not thought it worth while to discuss the case of the Dutch merchant ship, said to have been sunk in the Straits off Tarifa, and to have been washed up near Tangier. Ships do not sink and rise again like dead bodies. A ship laden with *brandy* and *oil* may, possibly enough, have been water-logged in the Straits, and have drifted to the westward inshore; but the story, as related, is altogether improbable, not only on hydrostatic, but on historical grounds.—See Smyth's Mediterranean, p. 155.

An absurd theory has been proposed with reference to the subject we have been considering, which is certainly not worthy of serious mention, but which is interesting as showing the extravagance of which the minds of ignorant men are capable. It is, that the excess of water in the Mediterranean runs into a big hole, causing the whirlpool Charybdis, gets heated in the central fires, and emerges somewhere in the Gulf of Mexico, to form the head of the Gulf Stream.

NORTH AFRICAN CURRENT as far south as Cape Verde, in the neighbourhood of which it divides into two; the greater part keeping straight on towards the south-west, gradually falling into and strengthening the Equatorial Current; the remainder following closely round the coast line, and turning with it to the east, into the Gulf of Guinea, from which it takes the name of the GUINEA CURRENT.

Having thus traced the principal currents of the North Atlantic Ocean, we readily see that the DRIFTS of the regions of the Trades and westerly winds, forced by the lay of the coast, and the pressure behind, form strong currents in the western and eastern parts of the ocean; that they thus, joining on to and falling into each other, constitute one uninterrupted circulation, in which they travel "with the sun,"* leaving, in the middle, a large area, where the water, free from their influences, is comparatively at rest, or runs to leeward, according to the varying direction of the wind. Into this central space collects a very large proportion of the drift or wreck which floats about the Atlantic, in very much the same way that the little bits of stalk will collect in the centre of a tea-cup when it is stirred round. There is here, also, a great quantity of a peculiar kind of sea-weed, commonly called *Gulf weed*, which bears small berries somewhat resembling the common burr, and has been said to grow, in the first instance, amongst the Bahamas, from whence it is torn by the action of local currents, and carried into the Gulf Stream. It may, however, be doubted whether the Gulf weed is altogether identical with the sea-weed of any coast, although specimens closely resembling it have been found in many different localities, not only in the Atlantic, but in the Pacific. It seems probable that, wherever it originally came from, it

* According to nautical usage, "with the sun" means from left to right, over, turning in the same direction as the hands of a watch.

has naturalized itself in its present locality, and has undergone various modifications to suit its new and peculiar mode of life.

It has the singular property of growing in the open sea, without touching ground; accumulating in this part of the ocean, it grows with its roots hanging freely to a depth of 60 or 70 fathoms, and at times is so thick that the surface of the sea has all the appearance of a pond of stagnant water, and the way of a ship through it, even with a fresh breeze, is very sensibly impeded. The locality where it grows was, therefore, called by Columbus and the early Spanish navigators, *Mar de Sargaço*, or the Sea of Seaweed, a name which, with a slightly different spelling, has become, in English, THE SARGASSO SEA. Its boundaries are somewhat variable, but it lies, on an average, between the parallels of 20° and 35° N., and between the meridians of 30° and 60° W., being of an irregular elliptical shape, and covering an area scarcely less than that of continental Europe.

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## SECTION III.

### THE CURRENTS OF THE SOUTH ATLANTIC.

IT is quite unnecessary to trace the currents of the other great oceans in the detailed way in which I have followed out those of the North Atlantic. My object has been to illustrate, in the first instance, and on the grandest scale, the action of the principles laid down; and to show how exactly those principles are in accordance with the facts which have been observed. For the rest, a mention of the name and direction of the more important currents will be, for the most part, sufficient.

In the South Atlantic, the BRAZIL CURRENT is the southern branch of the Equatorial Current, when it divides

on Cape St. Roque. It flows towards the south, in a direction nearly parallel to the coast-line, at a rate of from 12 to 20 miles a day; but, near the land, the south-easterly winds which prevail through the winter overpower it, and during this season the current runs to the northward. This set extends over a breadth of 100 or 150 miles, and beyond that, the southerly current is found throughout the year.

Joined by the stream of the La Plata,—which, during the rainy season, is an enormous body of water, and fresh and muddy, may be traced 200 or 300 miles to the eastward,—it falls into and strengthens the SOUTH ATLANTIC CONNECTING CURRENT, which is merely the northern side of the great Easterly Drift of the south temperate zone. A part of this easterly current, as it passes Cape Horn, closely follows the coast line,* and turns very decidedly to the north-east; a considerable body of very cold water is thus carried to the northward, along the coast of South America, and, forcing its way amongst the hot waters of the Brazil Current, produces alternating changes in the temperature of the ocean and the superincumbent air, which frequently manifest themselves to the most careless observer, in the form of dense fogs, near and to the south of the River La Plata. This northerly direction is communicated, though less markedly, to a very large portion of the Easterly Drift; it would seem that, whilst the water nearest the land is compelled to adhere to and to follow the line of coast, its influence draws after it the water which is more remote; that, partly by its turning to the north, still more, by its constant pull towards the east, away from the shores on the west, it makes, and continues to make, a partial vacuum, which alters, to some extent, the direction of the main body of the current.

With our present imperfect knowledge of the land in the

* *Ante*, p. 189, iv.

Antarctic regions, it is impossible to speak positively with regard to the share the southern coast-line may have in producing this inclination, towards the north, of the east-going DRIFT. Graham's Land, as laid down in our best maps, has a direction that must exercise very great influence on it; and the icebergs, which frequently reach the immediate neighbourhood of the Cape of Good Hope, seem to render it certain that the current which bears them thither has rasped against the shores of a snow-clad land.

However this may be, we know that the South Atlantic Connecting Current flows across the ocean, inclining, on its southern side, towards the north, until it feels the influence of the African coast. It then turns decidedly to the north, and, under the name of the SOUTH AFRICAN CURRENT, runs down the coast, strengthened by the prevailing southerly winds of the locality. It pursues this course till it reaches the Gulf of Guinea, when it is deflected towards the west, and, forming the easternmost origin of the Equatorial Current, flows alongside of the Guinea Current spoken of above, but in the opposite direction. The two waters do not mingle, for there is a very marked difference in their temperature; that of the Guinea Current being generally about 82°, that of the Equatorial Current about 75°.

This difference must be attributed to two causes, to the warmth of the easterly current of the North Atlantic, and to the coldness of the corresponding current in the South. In the North Atlantic, the easterly current is, to a great extent, a prolongation of the Gulf Stream, the hot waters of which are thus carried far to the eastward; it therefore preserves a relatively high temperature during a great part of its course; and although when it turns to the south, its waters are no longer noticeably hotter than those of the adjacent sea, they have not, on the other hand, the distinctive low temperature which would,

under other circumstances, belong to the waters of a current flowing from a high latitude into the tropics.

A large portion of the supply to this current is also furnished by a species of backwater, which, with very variable velocity and volume, runs to the eastward from the more western parts of the Atlantic, the waters of which have been for a long time subject to tropical heat. They thus, from a twofold reason, have, in the Gulf of Guinea, the full measure of heat due to that sweltering locality; whereas, the waters of the South African Current, a diversion of the cold Easterly Drift of high southern latitudes, bring into the tropics the slowly changing temperature which they contracted to the southward of Cape Horn.

Although in its general nature and full extent a DRIFT CURRENT, caused by the Trade winds of the North and South Atlantic, the Equatorial Current, according to the view which I have laid down here, is, in the eastern parts of its course, formed by the junction of two STREAMS —that is to say, of this deflection of the South African Current, which runs out of the Gulf of Guinea, and of that branch of the North African Current, which is thrown off to the westward in the neighbourhood of Cape Verde. There is thus within its boundaries, between these two streams, a triangular space, where the agencies, which produce the great westerly current, are somewhat restricted. Whilst to the north and south of this space,—lying between the parallels of 5° and 8° N., and to the eastward of the meridian of 50° W.,—the current is, in part at least, a STREAM, it is, in it, purely a westerly DRIFT, which ceases with the periodical interruption to the Trade wind in the summer and autumn. At this season of the year the current over this area is reversed, and flows to the eastward, sometimes with considerable velocity.

This reversed current, which is sometimes spoken of as the EQUATORIAL COUNTER-CURRENT of the Atlantic, has been attributed to the south-westerly gusts and violent squalls which occasionally interrupt the calms of the Doldrums; but though these may possibly give it, at times, an increased velocity, they are themselves so exceptional and short-lived, that it is in the highest degree improbable that they can generate, or even seriously affect a current which frequently runs at the rate of 60 miles a day, and which begins further to the west than they are commonly experienced. It is simply a species of *back-water*, of enormous size, but otherwise not very unlike that at the Fords of the Jordan, which I have described above; differing principally in this, that it is formed by two currents flowing away from a barrier, instead of by one. The southern branch out of the Gulf of Guinea, which has a far greater velocity than the northern Stream, and which flows more directly away from the coast, produces the greatest effect; but that of the other, from Cape Verde, is considerable. The two together, tearing the *dead water* away on both the north and south sides, cause the reverse current in the manner already explained.*

A reference to the map will at once show how very considerably this Equatorial Counter-Current must influence the quantity of water which enters the Caribbean Sea and supplies the Gulf Stream. It would seem, therefore, to be a point worthy of observation whether—and to what extent—the strength of this current affects the velocity with which the Gulf Stream issues through the Straits of Bemini; and whether, again, that initial velocity is, or is not, intimately connected with the changes of our English climate.

It has been shown that, on at least one occasion, a

* *Ante*, p. 189, v.

winter especially distinguished for its mildness, for its heavy and almost unceasing rains, and for the violence of its westerly gales—the winter of 1822—was also remarkable for the unusual warmth of the sea water in the Bay of Biscay and the eastern parts of the Atlantic Ocean ; a fact which suggests an unusual extension of the Gulf Stream towards the east.* Observations on this point have not been made with sufficient accuracy, nor are they sufficiently numerous ; it is, therefore, merely as a matter of speculation that I would call attention to the probability of establishing a direct connection not only between our winter climate and the velocity of the Gulf Stream in the Narrows, as has been already suggested by Sir Edward Sabine, but, going still further back, between it and the strength, extent, and duration of the Equatorial Counter-Current. The distance from its western extremity to the Land's End, as traversed by the continuous current already traced, is, in round numbers, rather more than 6,000 miles ; and assuming the mean velocity throughout this enormous distance to be from 40 to 50 miles a day, the period which must elapse from the time that that water approaches the Caribbean Sea from the eastward to the time when some portion of the same water washes our shores, or tempers our climate, is between four and five months. It follows, therefore, that should such a connection as I have suggested be found to exist, we might, from information of the state of this counter-current in July, August, or September, foretell, with approximate accuracy, the kind of weather we should have in December, January, or February.

By the deflection of the South African Current to the west, as part of the Equatorial Current, the circuit is com-

* Sir EDWARD SABINE : in the London, Edinburgh, and Dublin Philosophical Magazine, vol. xxviii. p. 317.

pleted in the South Atlantic as in the North; and in it also there is a central space, situated on the average between the parallels of 20° and 30° S., and between the meridians of 0° and 25° W., where the current is irregular and unsettled, following the wind. Drift and wreck probably collect here to a certain extent; but the absence of anything at all resembling the Gulf weed deprives it of the peculiarly distinctive character of the Sargasso Sea. It is, nevertheless, from geographical analogy, occasionally spoken of as the Sargasso Sea of the South Atlantic—a name which is convenient, and perhaps allowable, although not strictly and etymologically correct.

## SECTION IV.

### The Currents of the Pacific.

The Pacific Ocean, as compared with the Atlantic, has been but imperfectly explored, and but little sailed over. We have, however, sufficient evidence that the general system of its currents, both in the northern and southern hemispheres, bears a striking resemblance to that of the Atlantic. There is the Equatorial Current, which flows to the west with a velocity of from 10 to 20 miles a day. It preserves this direction across nearly the whole breadth of the Pacific, until it feels the pressure of the islands which form a barrier off the coast of Asia, and extend far to the south. On their eastern limit, south of the equator, these islands—New Ireland, the Salomon Islands, the New Hebrides, New Caledonia, the Feejee Islands, backed up by New Guinea, and by the northern part of Australia, form a nearly continuous line reaching to the Southern Tropic, in a south-easterly

direction, and cause almost the whole of the Equatorial Current to turn to the north.

The exact manner, constancy, and locality of this northerly deflection are still undetermined; observations which have any pretensions to accuracy are almost entirely wanting. We know, however, that during the southern summer, when the West Monsoon is blowing amongst the islands, and through Torres Straits, and reaching fitfully out into the Pacific, across several degrees of longitude, there is also an irregular eastward current running out into the ocean; and it seems probable that the northerly deflection of the Equatorial Current, south of the Line, takes place on its meeting with this set from the opposite quarter. The line of this meeting, either with an easterly current or with dead water, does, at any rate, sometimes show itself in a very remarkable manner; on one occasion, in latitude 2° 53′ S., and longitude 174° 55′ E., as a white line on the surface of the ocean, bearing the appearance of a low surf breaking on a sand-bank or reef. It proved to be an undulated line of froth or scum, several yards in width, extending on either side as far as was visible with the naked eye, and accompanied by a heterogeneous assemblage of floating mollusks, small fish, crabs, and other marine animals, drift wood, and oceanic birds. The birds were chiefly of the noddy and petrel families —some of them but recently dead. Of the mollusks, sea-snails were the most abundant: their number was immense, and their floats contributed greatly to the white appearance of the froth line.* This was, in May, the season of the East Monsoon among the islands; but the strong north-westerly current, which had been felt on the eastern side of this line, ceased immediately after passing it. Nevertheless, it is quite certain that very strong

* F. D. BENNETT: Narrative of a Whaling Voyage round the Globe, 1840, vol. ii. p. 62.

irregular westerly currents run at this season between the islands ; * but in these confined and shallow channels the tidal currents run with such force, and in such variable directions, that the oceanic currents, properly so called, can seldom be correctly estimated.†

In Torres Straits more especially, where the channel is much interrupted, where, on the north, the eastern extremity of New Guinea, on the south, the Great Barrier Reef quite overlap, and shut it out from the Pacific Ocean ; where the water is so shallow that a line of soundings, nowhere exceeding twelve fathoms, and that frequently broken by reefs and banks, runs right across from shore to shore, the tides run with very great violence ; but a true current, of even a few days' duration, is accidental ; and that continuation of the Equatorial Current, which is shown in many of our maps as ROSSEL'S DRIFT, has no permanent existence. But the northerly deflection, on the eastern side of the islands, is continuous, though it probably varies somewhat, with the seasons, both in position and in volume ; and being at all times pent in by the weight of water behind, it gradually assumes a more distinctive character, until, on the south-east coast of Japan, it becomes a powerful stream towards the north and north-east, which is now commonly called the JAPAN CURRENT.

This, like its North Atlantic counterpart, the Gulf Stream, has a deep blue colour, is hot, and intensely salt ; but it does not attain the same excessive velocity, since it is, in its origin, more unconfined, and is not forced into the ocean through any narrow channel, corresponding to the Straits of Bemini. A certain portion of this stream appears to follow up the coast-line of Asia, and passing between the

* A. R. WALLACE : The Malay Archipelago, vol. ii. p. 331, *et seq.*

† C. F. BEAUTEMPS-BEAUPRÉ : Introduction to the Practice of Nautical Surveying ; trans. and edit. by Capt. Richard Copeland, R.N., 1823, p. 8.

Aleutian Islands—on which it throws quantities of tropical drift-wood—to form a sluggish northerly set over the whole of the Aleutic, or Bering Sea, which runs through Bering Straits with no great velocity, but with a temperature which is still sufficiently high to render the ice in the neighbourhood of Point Barrow often rotten and unsafe, even in the middle of winter.

After passing Point Barrow, it runs in a north-easterly direction,* and may, occasionally in summer, be felt in its softening influence as far as the western opening of Banks Strait, beyond which it seems to have no climatic effect; though it is probable, and almost certain, that the gentle flow of its waters continues eastward, through Lancaster Sound, into Baffin's Bay, where it falls into the southerly current, which comes down through Smith's Sound, and joins the Arctic Current between Cape Farewell and the north of Newfoundland.

It is possible also that an insignificant branch of the stream through Bering Straits is deflected westward, where it may, in some seasons, clear, by its warmth, a channel through the ice north of the Kolyma district. It was here that Admiral Von Wrangell found open water—or what is now frequently called "a Polynia," an open sea—in 1820, and the following years;† but though it is thus certain that bits of open water are, at times, found in that neighbourhood, their permanent existence seems extremely doubtful; and it is, at least, impossible to admit that any small branch of the current through Bering Straits can produce such an effect, when we find that the main body of the current, far to the southward, although it sweeps into Norton Sound, and strews its shore with the pine trees washed down each year, in the early summer, by the Yukon, is unable to keep it

* Nautical Magazine, 1853, p. 29.

† Admiral FERDINAND VON WRANGELL: Expedition to the Polar Sea, Edited by Lt.-Col. Ed. Sabine, 2nd edit. p. 504, and *passim*.

clear of ice, not only through the winter, but until the end of April.* It would seem rather, more probable that the *latent* heat given out by water, as it turns into ice, is, at times, sufficient to prevent certain parts of the sea, far away from the land, from being completely closed. The heat, so made manifest, is said to produce a very well-marked effect on the climate of Siberia;† and keeps the Canadian lakes open through a very severe winter. Similarly, the Scotch lakes are rarely, if ever, frozen over; and, from the days of our boyhood, we have all familiarly known that a small pond will "bear" long before a large one.

The main body of the Japan Current becomes, however, a constituent part of the Easterly Drift of the North Pacific, imparting to it, not only strength and volume, but the high temperature which it bears with it to the opposite shores, and which has a very marked influence on the climate of North-West America. As this easterly current approaches the American coast it turns southward, and, strengthened by the prevailing northerly and north-wésterly winds, flows along the coast of California; and in the winter months, extends—in part—down the coast of Mexico. In summer, when southerly winds prevail in that locality, this branch is at all times feeble, and is often reversed; but the western-most part of the Californian Current turns to the west, as, on entering the tropics, it impinges on the dead water which, to a great extent, fills the main bight of the west coast of Central America, and driven by the North-East Trade becomes the beginning of the Equatorial Current.

There is thus here again a complete circuit, and analogy would point out that within this there is probably a central space of comparatively dead water, corresponding to the Sargasso Sea. There is not, however, sufficient evidence to warrant our saying positively that there is such a space.

* FRED. WHYMPER: Travel and Adventure in Alaska, p. 131.

† VON WRANGELL: *Op. cit.* p. 48.

The long passages between California and China are now all made in the heart of the Trade on the one hand, or of the westerly winds on the other, where ships get the full benefit of the current as well as of the wind; and it may be many years before we have any direct and satisfactory proof of the existence of a Sargasso Sea in the North Pacific.

In the South Pacific the lay of the barrier line of islands deflects, as I have already said, almost the whole of the Equatorial Current to the northward. A small portion only escapes to the south, and forms a southerly current of no great strength on the east coast of Australia, from Sandy Cape to Cape Howe. Close in shore this current is, on many parts of the coast, completely reversed, and forms backwaters to the north or south of the various headlands it rubs against,* but further seaward, it flows, for the most part, in a direction nearly parallel to the line of coast, and is perceptible for a distance of about 60 miles from the land; beyond that there seems to be at all seasons a set to the north-east, which occasionally, and more especially in winter, attains a very great velocity. This is a branch of the great Easterly Drift of the Southern Ocean, which, following round the coast, turns to the northward, in exactly the same way as it follows the coast of South America into the Atlantic. In winter this Easterly Drift, pent against the south coast of Australia by the almost continual and generally violent south-westerly winds, has, near the land, a velocity far beyond what it has in the summer months, so that, released from the pressure of the coast, driven also by the south-westerly gales, it rushes to the northward with great force, and flows past Lord Howe Island, and the other islands in that neighbourhood, at a rate which sometimes exceeds a hundred miles a day. It does not, however, appear to retain this exceptional velocity

* *Ante*, p. 189, v.—ADMIRALTY: Australia Directory, vol. i. p. 501.

for any great distance; and in the absence of any evidence to the contrary, may be supposed to die out in the open sea to the eastward.

Further south, it strikes against the western shores of New Zealand, and occasionally, at least, with force sufficient to make itself felt as a current diverging to the northward. The southerly deflection, on the other hand, is distinctly marked as a strong current scouring the coast of Middle Island, to the south of Cascade Point; running to the south-east, round the south-western promontories, and through Foveaux Strait, with a force that makes it impossible for sailing ships to pass through against it, without a strong fair breeze.

To the east of New Zealand, and south of the parallel of 40° S., the Easterly Drift prevails the whole way across the ocean. From many observations, not only of the positions of ships, which, taken from day to day, might be considered as not sufficiently accurate for determining small differences of longitude, but of the positions of icebergs, and enormous fields of floating ice, clearly recognised as the same, at intervals of one, two, or three months, this current appears to have an average velocity of from 10 to 15 miles a day in a direction nearly due east. These icebergs, torn off from the great field of Antarctic ice, more especially in summer, drift along for hundreds and thousands of miles without any important change in their latitude; and though it must be admitted that the current which carries them to the parallel of 50°, or thereabouts, tends towards the north, it may fairly be supposed that this tendency is due to occasional deflections from points and headlands of the Antarctic Continent of which so little is really known, and to the southerly winds which are frequent in very high latitudes.*

* It has been suggested that icebergs occasionally drift across both wind and current, in consequence of some peculiarity in their shape, on

That in the later months of summer, and in the immediate neighbourhood of Antarctic land, strong northerly currents have been occasionally experienced is certain;* but these currents are by no means constant in their flow, and the set is not unfrequently towards the south.† Sir James Ross appears to think that the currents he experienced, whether northerly or southerly, were drifts caused by the wind, and the observations are nowhere sufficiently exact to enable us to decide to what extent they were tidal; still it seems probable that when enormous masses of snow and ice are melting off the land, and trickling by millions of rills into the sea, they produce the effect of river streams, such as have been already mentioned as perceptible even for hundreds of miles off the mouths of the Amazon, Orinoco, or La Plata; a probability which is strengthened by the comparatively small quantity of salt generally found in the water of high southern latitudes. But it is impossible to believe that the summer melting of snow can produce a permanent current felt over 30 or 40 degrees of latitude, or can supply such an enormous body of water as is represented in most maps as the GREAT ANTARCTIC CURRENT, a current which comes no one knows whence, is fed no one knows how, and turns, no one knows why, towards the east in a manner

which the wind, or the current, or both combined, strike obliquely and act as the wind acts on the sails of a ship. It is said that in the South Pacific, icebergs have been seen setting to the northward across a strong west wind and easterly current, presenting all the appearance of a ship "on a wind." Such an accident of shape might account for the exceptional position of some few icebergs which have been reported considerably to the north of their usual track; as, for instance, one in lat. 43° S., long. 105° W. The idea is plausible enough, but, as a statement of fact, it wants confirmation.

* Sir J. C. Ross: Voyage in Southern and Antarctic Regions during the years 1839-43, vol. i. pp. 207, 211, and *passim*.

† *Ibid.* vol. i. pp. 204, 222, and *passim*. See also a letter from Captain Wilkes, U.S.N. in vol i. p. 348.

quite contrary to the favourite theory of a change in direction caused by the rotation of the earth. As a matter of fact there is no such current. The Easterly Drift does not indeed always run due east; its course sways backwards and forwards through several points of the compass, and in the higher latitudes, where the winds prevail from the south of west, inclines somewhat towards the north, but the northing is nowhere conspicuous; and as a current with a mean easterly direction, it appears to extend as far to the south as we have any positive knowledge. In the more temperate latitudes, it flows without interruption until it nears the coast of America, where it divides; one part of it, south of the parallel of 45°, pressing to the south, and following the line of coast, passing round Cape Horn to the eastward, turning to the north-east past the Falkland Islands, and so into the Atlantic, as has been already described. The other part, north of 45° S., turns to the north, and carries with it into the tropics the low temperature which its waters contracted in high latitudes. This current, commonly known as the PERUVIAN COLD CURRENT, is also frequently called HUMBOLDT'S CURRENT; that distinguished observer having been the first to turn attention to it, and to the effect which it produced on the temperature of the sea, even in the low latitudes of the Peruvian coast. Further to seaward, the northerly, or north-easterly set has been called MENTOR'S CURRENT, after the Prussian merchant ship, "Mentor," which more particularly noticed it in the year 1823; but as it is undoubtedly nothing more than an extension to the westward of the same current which washes the shores of Chili and Peru, a different name seems uncalled for, and therefore unadvisable. The intrusion of this large body of cold water into warmer seas causes a dense fog on the coast of Chili, whenever a northerly wind blows, as frequently happens in the winter months; this fog thus at times con-

tinues for many successive days or even weeks, and, by a curious mistake, has been said to be the *cause* of the coldness of the Peruvian Current.

The course of this current, uniform as it generally is, is, however, subject to occasional interruptions. After a few days of strong north-west winds in May, 1835, H. M. Ship "Challenger" went on shore near Mocha. The error in her reckoning amounted to more than 40 miles, which Admiral Fitzroy, who was on the coast at the time, thinks can only be accounted for by the supposition that the current had been, for the time being, reversed, and that the ship had experienced a strong set to the southward and eastward.*

This, and many other disasters, notices of which abound in our naval histories, show how very little implicit confidence is to be placed in the regularity of the flow of even the best known currents, and point out the absolute necessity of constant watchfulness on the part of the navigator.

Partly, perhaps, by the coast-line, which trends to the west as far as Cape Blanco, but more by the dead water, which lies to the northward in the great bight of the west coast of Central America, the Peruvian Current is deflected to the westward, and forms the southernmost origin of the Equatorial Current, just as the corresponding deflection of the Californian Current forms the northernmost, and in very much the same way as the South and North African Currents turn to the west in the Atlantic. And, as in the Atlantic, there is between the two a gigantic backwater, running towards the east, which is spoken of as the EQUATORIAL COUNTER CURRENT of the Pacific.

This current is represented in Johnston's Physical Atlas, as between the parallels of 5° and 10° N., and reaching back to the westward as far as the meridian of 145° or 150° W; but the observations are not sufficient to

* Voyage of the "Beagle," vol. ii. p. 280.

warrant our believing that this enormous length is at all common; indeed, little seems to be known about it, except that it has been occasionally reported; and a comparison with the similar counter current in the Atlantic would lead us, in the absence of evidence, to suspect that it is neither permanent in its flow, nor constant in its direction.

Similar backwaters appear frequently to form on the west side of many of the islands and island groups which dot the intertropical Pacific. These have never been exactly determined, but are, so far as we know, irregular; coming and going according as the strength of the Great Equatorial Current increases or diminishes, or as its actual direction, for the time being, changes through a few points.

Of any currents which may exist in the central region of the South Pacific we have no notice, and there is reason to believe that they are not only trifling, but mere casual drifts, caused by whatever wind may happen to blow for a few consecutive days.

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## SECTION V.

### The Currents of the Indian Ocean.

In the South Indian Ocean, the South-East Trade, blowing freshly the whole year, causes a strong westerly set between the Tropic of Capricorn and the parallel of 10° S., north of which it is held back during the prevalence of the North-Westerly Monsoon of the summer months. This monsoon, however, in the western part of the sea, blows more from the north, and from the eastward of north;* and, aided by the North-East Monsoon of the North Indian Ocean, causes a southerly drift, which reaches as far as Madagascar, and runs through the Mozambique Channel. In all the different seas on the face of the earth, there is no place where the

* *Ante*, p. 82

action of the Odorator, as already described,* is more powerfully illustrated. The great body of the intertropical westerly Drift, deflected to the southward, along the east coast of Madagascar, and pressed to the west by the weight of water behind, runs past Fort Dauphin and towards the African coast as a stream of very considerable magnitude. As it crosses the southern entrance of the Mozambique, the water is dragged out of the narrow channel with a violent force which gives it a velocity that is elsewhere almost unheard of. It is said that, at times, it runs past Cape Corrientes at the rate of 130 or 140 miles a day—a rate which is, however, quite exceptional; 80 or 70 miles, or even less, being much more common.

In the winter months, the prevailing wind in the channel is from the south or south-west; and the current, driven by it, flows to the north. At the same season, the westerly Drift outside extends nearly to the equator; and, as it approaches the eastern shores of Madagascar, is deflected towards the north, from about the parallel of 15° S. This being pressed by the westerly set behind, streams obliquely across the northern entrance of the Mozambique, and violently drags out of it the water, which has already a certain northerly drift. The South-West Monsoon, also, is then blowing north of the Line, sweeping away the water from the western side of the ocean, and sucking, as it were, a fresh supply out of the Mozambique, and from the sea north of Madagascar. It is impossible to assign its correct value to each of these causes; combined, they give this northerly current a velocity which is frequently as great as fifty, occasionally as great as seventy, miles a day, as far as the parallel of 5° N.

But in the channel itself the current at this season is very uncertain. Whilst this powerful stream across the north end is dragging the water out of it there, another,

* *Ante*, p. 130.

quite as powerful, if not more so, is dragging the water out of it to the southward. The water in a confined channel can clearly not afford a continuous supply to two streams, one towards the north, one towards the south; and thus, though it has a general northerly tendency, it is subject to great variations, not only from day to day, but in different localities, and is frequently found running up on one side, and down on the other; and again, at other times, running in quite the opposite direction, so that it cannot be in any way depended on or trusted. This doubt would of itself be sufficiently embarrassing to navigators; but a mistaken theory and a mistaken nomenclature have given rise to a description of the currents in this part of the ocean, which is not only false, but in the highest degree dangerous. On the assumption that hot equatorial water will, by the difference of its specific gravity, flow towards the pole,* the strong warm current found to the south-west of Madagascar has been supposed to flow necessarily out of the Mozambique. It has therefore been called the MOZAMBIQUE CURRENT, and—under the sanction of such a name, and the theory which originated it—has been very commonly described as running to the south from the neighbourhood of the equator, through the Mozambique Channel; and ships to the north of Madagascar have frequently found themselves awkwardly situated, in consequence of a set in what has seemed the wrong direction. Instead of this erroneous name, I would suggest that of the NATAL CURRENT, restricting the name of MOZAMBIQUE CURRENT to the irregular alternating current, which flows with moderate velocity through the Mozambique Channel, northward or southward, according to the season.

But the NATAL CURRENT, a mighty stream, and, with the exception of the Gulf Stream, the most powerful ocean current of which we have any knowledge, flows per-

* *Ante*, p. 201.

manently to the southward. It passes along the coast of Natal at a rate varying from 50 to 100 miles a day, tearing violently at the shore, and—wherever the nature of the land permits—effecting continual alterations in the coast-line, cutting through headlands, carrying away small islands, or laying down others with the mud it forces along;* and continues its course to the southward, till, deflected to the eastward by the Agulhas Bank—a bank formed almost beyond a doubt by the detritus swept down from the northern shore—it pours the greater part of its waters into the Easterly Drift, which, driven by the prevailing westerly winds, passes the Cape of Good Hope from the Atlantic into the South Indian Ocean.

It thus carries into the cold drift current a vast body of very warm water, the high temperature of which is very sensibly felt through many hundreds of miles to the eastward,† and has occasionally, when the stream has a velocity even greater than usual, been noticed very far to the southward. It is probably to this mingling of hot and cold water that we must attribute the fogs, for which the vicinity of Prince Edward's Island, Crozet's Island, or Kerguelen Land, is so notorious. Observations of the temperature of the sea in that neighbourhood show very remarkable irregularities and sharply defined differences; and it would appear that the easterly current impinging on these islands is in part deflected to the north, so that the cold water of 47° or 50° south latitude is shot two or three degrees to the northward, into water comparatively warm, not so much by reason of the difference of latitude, as in consequence of the extended influence of the Natal Current.

A certain small portion of this powerful stream is not deflected to the southward; it follows closely the line of

* Lyons McLeod: Travels in Eastern Africa, etc. vol. i. 151.

† Capt. H. Toynbee, in Journ. of the Roy. Geog. Soc. vol. xxxv. p. 150.

the shore, over the Agulhas Bank, and, turning to the northward, round the Cape of Good Hope, adds its waters to those of the South African Current already described. The two, however, do not mix for a considerable time. Their temperatures are so different that they run together in streaks, the hot water apparently forming itself into narrow bands over the cold. In shore, the easterly tendency of the cold water drives it up the shelving bank, and its low temperature may be distinctly traced far down the coast, when, to seaward, the thermometer, in the surface water running in the same direction, stands ten or fifteen degrees higher.*

This branch of the Natal Current, which, when it runs to the westward, over the Agulhas Bank and round the Cape, has been called the AGULHAS CURRENT, has no great strength. Its velocity varies from 20 to 30 miles a day, and is occasionally advantageous to homeward-bound ships, enabling them to slip past the Cape to the westward against the prevailing westerly wind. The propriety of such a course is, however, questioned; the weather on the Agulhas Bank is notoriously bad, and the comparatively shallow water, subject to the condition of *stream against wind*, rises in a heavy, often in a very dangerous, sea, which led the early navigators to give the Cape of Good Hope the appropriate name of the Cape of Storms.

The Easterly Drift of the temperate latitudes crosses from Africa to Australia, at the mean rate of from 10 to 20 miles a day, without any noteworthy change of latitude. When near Cape Leeuwin it divides, and whilst a large portion of it flows along the south coast, in the manner already spoken of, the northern part turns to the north-east or north. Unconfined by the nature of the coast-line along which it runs, and free from pressure behind, except in the higher latitudes, it has scarcely any of the marks which

* Journ. of the Roy. Geog. Soc. vol. xxxv. pp. 149, 301.

distinguish the Stream Currents. It becomes, in fact, a mere northerly Drift, held back or reversed by the occasional northerly gales. A peculiar feature of this reversion is, that near the coast it very commonly precedes the change of wind, and is looked on as *foretelling* a gale from the northward. The storm, slowly advancing, banks up the waters of the current, drives them before it, and the pressure is felt many miles, or hundreds of miles, to the southward. Such a reversion is rare, except in Drifts, or half-formed Streams; in them a violent change of wind is almost invariably found to produce the same effect; and to doubt its power in this instance—to look for other cause, or to suspect some paltry difference of specific gravity—is much as if Polonius, slain behind the arras, were to say that the inherent attraction of matter drew the point of the rapier to his body; and that the hand of Hamlet, unseen, and four feet distant, could not possibly have anything to do with the deadly thrust.

In the North Indian Ocean the alternating nature of the winds causes similar alternations in the currents; and wherever the monsoons blow, the currents run in the corresponding direction, during the same season of the year. These are for the most part merely DRIFTS, though, on the Malabar and Coromandel coasts, they assume somewhat of the nature of STREAMS, and flow round Cape Comorin and through the Gulf of Manaar from west to east, or from east to west, according as the summer or winter Monsoon rules. On the African coast, also, the northerly current of summer has a great velocity, running occasionally at the rate of 80 miles a day, until, on approaching the island of Socotra, it ends in a series of eddies and large irregular whirlpools; but the southerly set of winter on the same coast is equable and gentle, rarely exceeding a rate of 24 miles.

Notwithstanding the irregularity of the monsoons in the Gulf of Aden, the alternation of the currents there, as well as in the Red Sea, is very strongly marked. During the winter months the westerly set of the Arabian Sea, collected to a considerable extent in the funnel-shaped Gulf of Aden, is forced to the northward through the narrow passage of the Straits of Bab-el-Mandeb, at a rate of from 30 to 40 miles in the 24 hours. This is entirely reversed during the summer: the South-Westerly Monsoon in the Arabian Sea causes an easterly current, which draws the water out of the Gulf of Aden, in very much the same way as liquid scent is drawn out of the Odorator already described. At the same time, the strong northerly wind prevailing in the Red Sea causes a southerly current in that long narrow streak of water; the two together produce a current which from June to September runs to the southward through the Straits of Bab-el-Mandeb with a velocity of 40 miles a day.

The current in the Straits of Bab-el-Mandeb and in the Red Sea, a sea which until lately offered few advantages to the trader, and, on account of its many dangers, and the consequently heavy insurance, is but rarely visited by European sailing vessels, has been hitherto considered of comparatively little importance; but it becomes important by reason of the illustration, amounting to decisive proof, which it affords of the superiority of wind over all the other *ordinary** forces, which can be considered as even probable causes of a current in the sea.

Captain Maury, who, on the contrary, considers the influence of wind as slight compared with that of other agencies, has shown that the excessive evaporation in the Red Sea must, by lowering the surface, cause a northerly

* By the word *ordinary*, I exclude the forces which cause exceptional rushes of water, such as *storm waves*, of which I shall have to speak further on; or *earthquake waves*, such as caused such damage on the coast of Peru in the autumn of 1868.

current; and has, in consequence, supposed that the water does run in at the rate of 20 miles a day.* His theory is perfectly correct, so far as the difference of level is concerned; and that difference would doubtless produce the effect he describes, were it not counteracted by other forces; but the absolute opposition between the results of his theoretical reasoning and the facts determined by observation, is a conclusive proof that he has argued from a false basis, and shows how dangerous it is, in treating of a science so complex and intricate as the motion of fluids—a science of which so very little is really known—to build on any other foundation than observation and experiment.

The fact that the current runs strong out of the Red Sea during the hottest months of the year—that is, during the months when evaporation is most active and the difference of level at the greatest—whilst it runs into it as strongly during the winter, when evaporation is feeble, shows us that there, at least, the effect due to such evaporation, and such change of level, is insignificant in comparison with that due to a steady persistent wind. I have, on a former page, dwelt on this same point as illustrated also by the Gibraltar Current; and when to this we add the fact that a current, changing with the wind, sets frequently through both the Sound and the Great Belt into the Baltic, a sea which is certainly not subject to excessive evaporation, we are, I think, justified in concluding that evaporation, whether by changing the level or by changing the specific gravity, is not the cause which produces the effects observed.

And, considering that in each of the great oceanic basins there is, on the west, a hot salt current setting from the tropics towards the poles; on the east, a cold or comparatively cold and fresh current setting from the higher latitudes towards the equator; and in the centre, a wide

* Sailing Directions, vol. i. p. 78.

district where there is no decided current either way; considering also that the relative expansion of water by heat, or the contraction of it by moderate cold, the increased saltness of the water in the tropics, or the approximate freshness of that in the polar seas, must produce forces, which, whatever be their value, act *in the same direction* across the whole breadth of each ocean, from shore to shore, I conclude that the supposed differences in density, due to these agencies, are not sufficient to set and to keep large bodies of water in motion.

And since several currents turn in a direction opposite to that which might be due to the rotation of the earth—not only the Gulf Stream, as already spoken of at length, but also, amongst others, the Guinea Current, the Natal Current, the Agulhas Current, and the eastern branch of the Californian Current—I believe that the rotation of the earth does not exercise that influence on the direction of the currents which has been supposed.

Lastly, considering that the great westerly and easterly currents of the tropical and temperate zones flow in the direction of the winds that prevail in those regions, that many other currents flow also in the direction of the prevailing winds, and are frequently retarded or reversed by any considerable change in those winds — that those currents which flow in a permanent direction, irrespective of the wind, are powerful STREAMS, restricted in their breadth by lines of coast, or by pressure of water, till they attain a depth and velocity which carry them onward free from surface influences, but in every instance, which I have been able to trace, in accordance with one or other of the principles laid down in the early part of this chapter, I conclude that *wind*, acting not only on the surface of the sea, but, by means of intense friction, to a considerable depth, is the chief—I will not say the only—*cause* of the numerous oceanic currents; and that though the water,

once in motion, frequently flows contrary or transverse to the direction of the wind, in appearance independent of it, it is in appearance only; that the motion is in reality as dependent on the wind, as is the motion, whether forward or backward, of the water in the tub represented in the figure on page 177, dependent on the pressure that drives the stream out of the pipe.

The natural laws which regulate the motions of fluids present problems too complex to admit of any satisfactory mathematical investigation; they are on that account none the less fixed; where fluid moves, it is under their guidance and restraint, whether the motion is produced by a sherry-cobbler straw in a finger glass, or by thousands of miles of wind in the expanse of ocean.

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## SECTION VI.

### The Climatic Influence of Currents.

In a preceding section I had occasion to call attention to the softening influence which the Gulf Stream exercises on the climate, not only of our own country, but of North-Western Europe generally; and from the considerations which I then brought forward, it is quite evident that if, from any cause, the direction and velocity of the Gulf Stream were such, that it either did not flow towards our shores, or had not velocity enough to reach them, our climate would be very much more severe than it is. Reading ancient and mediæval histories, it is impossible to avoid the conclusion that our winters are now far less rigorous than they were several centuries ago; and though, as I have shown, this may be partly due to clearing, cultivation, and drainage, there are solid grounds for believing that a great part of the change is due to a change in the direction and velocity of the Gulf Stream; and it is quite certain

that the formation of the land which gives it its present direction and velocity is of very recent date.

The banks of Newfoundland, one of the principal causes of the permanent deflection to the east, are even now forming, and may very probably have had, a few hundred years ago, such a different shape and depth as to deflect the stream at a very different angle. Some portion of it may then have found its way to the northward, along the coast of Greenland, and have imparted to it that milder climate which the ancient Icelandic records speak of, and permitted that luxuriant vegetation to which the country owes its name, and which so suddenly and mysteriously vanished about the beginning of the fourteenth century.* Even now, beans of Mexican growth are often washed up on the Greenland shores, and are considered by Admiral Irminger, whose labours have so largely added to our knowledge of the hydrography of these northern seas, as affording a very clear proof that a branch of the Gulf Stream does still occasionally press into Davis' Straits.†

But changes in the peninsula of Florida may probably have produced greater effect than even those in the banks of Newfoundland. This peninsula is composed almost entirely of coral or coral sand; it is the result of the work of the coral insect through hundreds and thousands of years—work that, at the southern extremity, amongst the Tortugas, reefs and keys, or to the eastward, amongst the Bahamas, is still going on as busily as ever. It is a well-known fact that the polype which forms the coral reef cannot work below a certain depth—about 15 or 20 fathoms.‡ The Gulf of Mexico and the open ocean out-

* Lord DUFFERIN: Letters from High Latitudes, p. 55—C. MARKHAM: On the Greenland Esquimaux, in Journ. of the Roy. Geog. Soc. vol. XXXV. p. 89.

† J. G. KOHL: Geschichte des Golfstroms, 1868, p. 160.

‡ Corallines of a different and, till now, unknown species were dragged

side have both a depth which would render it impossible for the creature even to exist; before it could have begun to build it must have had a shoal for its foundation. There are strong grounds for believing that this shoal was simply a secondary bar of the Mississippi. Great quantities of mud brought down by that river would be carried eastward by the current, which then, as now, ran along the coast of Louisiana, and would be dropped where that current clashed with the westerly drift outside. On the shoal so formed the coral insects have built, and the result of their labours appears as a long, narrow strip of land and numerous islands and reefs, amongst which the confined current has dug out for itself a channel, to a depth which, for the present, prevents it from being further blocked up.*

The peninsula of Florida is now a low, flat country, rising only a few feet or even a few inches above the sea level, and containing many swamps and lagoons of considerable size; but at no distant period it was a mere collection of islands, reefs, and banks—not unlike the present Bahamas—through the midst of which the waters, driven into and round the Gulf of Mexico, would freely escape without any very sensible alteration in the velocity of the current. The Gulf Stream could not then have its peculiarly distinctive character, and its effect on the climate of Europe, even if it turned in that direction, must have been very trifling. The gradual closing up of the channels by the ceaseless work of these polypes has, by diminishing the outlet, increased the force of the stream; but it is no wild conjecture that a thousand or five hundred

•up from a very great depth during the recent expedition of the "Porcupine;" but it does not appear that these are in any way directly connected with the creature that builds reefs, or that it is necessary to modify the views respecting it, which Mr. Darwin has established.

* KOHL: *Op. cit.* p. 198.

years ago the water escaped through a much wider passage, possibly through several passages, with a velocity far inferior to that which now shoots it across the ocean to the European coasts.

It may fairly be supposed that a still wider opening of these passages, or the absence of the coral banks altogether, was, thousands of years ago, coincident with that epoch in the physical history of our country when the valleys of Wales, of Cumberland, and of Scotland were filled with huge glaciers slowly grinding their way towards the sea. That such was the case in what is known to geologists as the Recent period—that is, since the surface of the earth became, as a whole, very like what it is now, and the various races of animals and vegetables became similar to, or even identical with, those of the present time—is quite certain. The wearing action of glaciers on rocks over which they have passed cannot be mistaken for anything else; and the frequency of such marks in the valleys of our mountain districts proves, beyond the possibility of doubt, that at no very remote period the climate of Great Britain closely resembled that now known in Greenland.

We cannot believe that at that time, under such circumstances, any current at all resembling the Gulf Stream washed the north-western shores of Europe; and if, as many geologists maintain, the glacial period in North America was contemporary with that in Europe, it is difficult to avoid the conclusion that no warm current then passed up along its eastern coasts. Recent investigations have thrown new light on the probable escape of the warm water forced westwards by the Equatorial Current; they have shown that a large proportion, at least 30 per cent, of the fishes which live in the Gulf of Mexico and in the Caribbean Sea are found also on the west coast of Central America: "The specimens examined from opposite coasts of the isthmus are absolutely identical, and there is not

the slightest indication that one of them has been modified or degenerated into a climatic or local variety."* That such is the case appears to be conclusive as to the existence, at no very distant period, of open channels through the isthmus—channels which, now stopped by volcanic action, by the upheaval of the land, may very possibly have been in those districts of small elevation, as from Aspinwall to Panama,—by Lake Nicaragua—or from the bottom of the Bay of Campeachy, through the Isthmus of Tehuantepec, each of which has been, at different times, asserted by eager speculators to be the one proper route between the oceans, the only feasible line for railroad or canal.† We have, of course, no possible means of judging when this upheaval took place, and, by stopping the channels, formed the germ of the Gulf Stream; but there is reason to believe that long after the glacial period, our climate continued to be very severe. The musk-ox, an animal now confined to Melville Island and the neighbouring country in the Arctic regions, and to the plains bordering on Hudson's Bay, has left evidence of its existence in England, France, Belgium, Germany, and most of middle Europe, where, too, reindeer seem to have been abundant, down almost to the dawn of history.‡

But although the absence of the Gulf Stream from our shores may have had a considerable share in producing this remarkable climatic difference, such a share would be, comparatively speaking, a passive one: there must have been a more active cause for a result so intense as that borne witness to by the traces of the glacial period; and there is strong evidence in support of the opinion that

* Dr. ALBERT GUENTHER: On the Fishes of the States of Central America, in Trans. of Zool. Soc. of London, 1868, p. 399.

† Captain BEDFORD PIM, R.N.: Gate of the Pacific, *passim*.

‡ ANDREW MURRAY: Geographical Distribution of Mammals, 1866, p. 140—Sir CHARLES LYELL: Antiquity of Man, 1st edit. p. 185, etc.

this cause was a current out of the Arctic. Geological research has collected evidence, which amounts to positive proof, that the whole of Denmark and Western Germany, of Eastern Scandinavia, and, further north, of Lapland, was at that period under water; and that a polar current, laden with icebergs, flowed over what is now the lowland of England and Scotland, and washed the shores of the more elevated districts. I have just spoken of the unmistakeable marks left by the action of glaciers; those made by icebergs grinding heavily over shoals in a shallow sea are as easily to be distinguished; the deep grooves which the stones they carry with them, frozen into their under surface, cut in the ground they rub on, are as plain as is the mark made by a glazier's diamond on a sheet of glass. These marks, these deep scratches, are found everywhere—in England, in Sweden, in Lapland—wherever the nature of the rock permits us to expect that they could last through the weathering of many centuries; and always running in a north-east and south-west direction.* On many parts of the same line are found those singular boulders, generally isolated and different from any rock in the neighbourhood, which are now pretty commonly known as "dropped stones." Like the striæ or scratches, these stones are everywhere; in the east or the north of our own country they are plentiful, wherever the progress of cultivation has not caused them to be grubbed out or broken up; on the moorlands of other countries they are as plentiful, or more so: and, like the striæ, they all point in the same direction; they must have come from the north-east, borne by icebergs, and have been dropped in their present position far, hundreds of miles, from any living rock of the same nature. All along our eastern shores lie blocks of granite which can only have come from Sweden or Norway; and similar boulders may be traced in a continuous stream from

* Prof. RAMSAY: in Peaks, Passes, and Glaciers, 1st series, p. 453.

those countries to Denmark and across the Elbe, through Westphalia to the borders of Holland.* The quantities of sea shells of now existing species found in Lapland up to a height of 600 feet; and the evident marks of sea action at a much greater height, where in a wild country a close search for shells has not yet been made, may be considered as establishing the fact that the land is of comparatively recent elevation; a fact which, considered in connection with the numerous striæ and dropped stones, to be traced in direct sequence from the watershed north of the Gulf of Bothnia to the valleys of the Thames and Severn, is sufficient to convince us that a Polar Current long ago flowed down to the east as well as to the west of the elevated district of Norway, the present Dovrefjeld, bringing its ice and its intense cold round the small portion of our country which then peered above the surface of the sea.†

The traces, which are found in many parts of the globe, of a climate differing widely from that of the present time, have been a fruitful source of wonder and wild speculation. The discovery, in the icy regions north of America, of fossils, both animal and vegetable, of species which exist only in warm or temperate countries, of fishes which are not now found north of the parallel of 40° N., seems to prove that where Franklin and so many others of our countrymen have, in these modern times, perished from the severity of the cold, amid ice-bound seas and snow-clad hills, the waters were once warm as those of the Mediterranean, the shores were once green with a forest growth similar to that of Madeira.‡ The marks of ice, in localities

* LYELL: Ant. of Man, p. 218.

† LYELL: Principles of Geology, Tenth Edit. chap. x.—Ant. of Man, chap. xiv. xv. and xviii.—Frost and Fire, *passim*.

‡ Mr. Darwin has pointed out that too much stress should not be laid on these indications, as there are now existing peculiarities in both the

where neither ice nor snow could now exist for more than a few days, if for more than a few minutes, speak as decidedly of some great change in the very opposite direction. In the Lebanon, for instance, the evidence of glacier action is still distinct, and as unmistakable as it is in Switzerland or in Wales.

To account for these remarkable changes, and for the extreme contrast to the present state of the world, with which we are familiar, various theories have been put forward. The most favourite of these was, for some time, that which suggested that the axis of the earth has been altered; that polar and tropical latitudes have been interchanged, whether by a slow and gradual movement, or by some tremendous convulsion of Nature: but the figure of the earth, a spheroid flattened at the poles, may be accepted as an absolute dynamical proof that such a theory is false, and that the axis of the earth is the same now as it always has been.

It has, from another point of view, been suggested that during the glacier period, the heat of the sun was in some way diminished, or obscured, or that our solar system was passing through some part of space peculiarly chilled, or in some other way subject to general refrigeration. That this cannot have been the case; that the glacier period was not a period of cold over the whole surface of the globe, as such a theory would require, is demonstrated by Professor Tyndall with his usual neatness and accuracy. His argument amounts to this—The ancient glaciers were of enormous size. In Switzerland, where their traces have been examined more carefully and exactly than elsewhere, it is seen that, grand as the present glaciers are, "they are mere pigmies in comparison with their predecessors."

flora and fauna of Tierra del Fuego which,—in the same way,—may tell the geologists of the future that the climate of that unfavourable island was semi-tropical.—See Journal of Researches, etc. p. 243.

To produce such glaciers, the quantity of snow must have been enormous; and to permit such a snow-fall, the quantity of aqueous vapour in the air must have been absolutely very great. Cold cannot produce snow if it has no aqueous vapour to act on; without heat, there can be no aqueous vapour; and without great heat there cannot have been such volumes of aqueous vapour as would be necessary to produce these ancient glaciers. "Vast masses of mountain ice indicate, infallibly, the existence of commensurate masses of atmospheric vapour, and a proportionately vast action on the part of the sun. In a distilling apparatus, if you required to augment the quantity distilled, you would not surely attempt to obtain the low temperature, necessary to condensation, by taking the fire from under your boiler; but this, if I understand them aright, is what has been done by those philosophers who have sought to produce the ancient glaciers by diminishing the sun's heat. It is quite manifest that the thing most needed to produce the glaciers is an *improved condenser*; we cannot afford to lose an iota of solar action; we need, if anything, more vapour, but we need a condenser so powerful, that this vapour, instead of falling in liquid showers to the earth, shall be so far reduced in temperature as to descend in snow."*

On the other hand, it has been suggested that the Arctic regions may have owed their once genial climate to an intensified emission of heat from the sun; or to the internal heat of the earth making itself felt through the solid crust. It is, however, easily shown that such an increase of solar

* Heat, as a mode of Motion, § 241.—As to the enormous size of these ancient Swiss glaciers, see Dr. OSWALD HEER: Die Urwelt der Schweiz, 13tes Kap. Dr. Heer considers that the retreat of these glaciers is due to the elevation of a great part of what is now North Africa, the conversion of sea into the Desert of the Sahara, and the consequent warmth of the southerly winds which now melt the snow. *Ibid.* p. 587.

heat cannot have taken place during the present ordering of the world. The mean temperature of the fortieth parallel may be estimated at 63° F.; and this temperature transferred to the seventieth parallel, would correspond to a temperature of 184° F. at the equator, and to 118° even in England.*

There is no reason to suppose that the climate of England has ever approached to such a mean, a degree of heat which is now unknown, except occasionally in the deserts of Africa, Asia, or Australia; but a temperature of 184° F., as a mean, is simply incompatible with the existence of animal life, such as we know it. In a sea of such a temperature, fishes would be cooked; beasts, scarcely able to breathe the burning air, unable to drink the almost boiling water, would be miserably scalded to death by the first heavy rain; and the eggs of birds would be roasted in the nest, as we now roast them in a heap of hot ashes. But the mild Arctic climate was coincident with many now existing species; and we may therefore conclude that it was not caused by any such increase of solar heat.

A similar objection may be offered to the hypothesis of so late a manifestation of internal heat. An addition of 30° or 40° to the mean temperature of the surface of the earth, would cause, in the tropics, a degree of heat unsuitable for living beings of the present or kindred species; and though it is highly probable that, in the most distant ages, the earth's surface, only recently solidified from a mass of liquid fire, had an exceedingly high temperature, this must have cooled down long before the now existing races of animals began to appear. Any difference therefore due to this cause cannot have had any share in producing the differences of climate of which I have been speaking; and

* Calculated from Sir David Brewster's formula, $t = e \cos l$, where $e$ is the mean equatorial temperature, and $t$ the mean temperature of any given latitude $l$; the present value of $e$ is assumed as 82° F.

with regard to the other theories to which I have alluded, there seem to be satisfactory and conclusive reasons for believing that the relation of the earth to the sun has never, since it first appeared in space, been sensibly different from what it is now.

Neither can I agree with those who maintain that these strongly marked alterations in climate are due principally to periodically recurring changes in the eccentricity of the earth's orbit, or in the obliquity of the ecliptic. These changes, whilst they tend to make the winters more severe, tend also to make the summer heat more intense; and I see no sufficient reason to believe that any excessive accumulation of ice or snow—such as marked the glacial period—could result from such a cause.*

But, on the other hand, it is absolutely certain that the distribution and relative position of land and water is, and always has been, continually changing. There is scarcely a mountain, however high, which does not show marks of having been once under the sea. Shells and fossil fishes have been found at the greatest known heights of the Andes and the Himalayas, the Lebanon and the Alps. The great plains of Africa, and of North and South America, were levelled at the bottom of the ocean. The rise and fall of the surface of the earth, elevation in one place, depression in another, has been ceaselessly going on; and in all time, the formation of a new coast line, or any great change in an old one, the interposition of a new country, or the disappearance of one formerly existing, must have caused a change in the currents of the neighbouring sea.

I have already shown how closely currents are connected with the lay of the coast, and how great an effect they have on climate. I have shown how, in the one instance which circumstances enable us to investigate in detail, a change

* LYELL: Principles of Geology, chap. xiii.

of current and of climate has, in all probability, been brought about; and though it would be wild in the extreme to venture on any conjectures as to the particular alterations in the great map of nature which have produced the very great alterations in climate, I see no reason to doubt that in former ages, now exceedingly distant, and in periods extending over thousands or millions of years, there have been changes which caused a *hot current*, with a temperature far beyond that of the Gulf Stream, to flow through the Arctic Sea, or a *cold current*, much colder even than that now on the coast of Peru, to flow across the equator. The climatic effects of such currents would be enormous; and, together with a difference in the height of certain mountain districts, may well have been sufficient to account for the many extreme changes which have been noticed.

## CHAPTER V.

### The Primary and Secondary Currents of the Atmosphere.

In former chapters I have pointed out how entirely the principal atmospheric currents divide themselves into two families—into winds from the east, and winds from the west. I have described the theory which, with some differences of detail, Hadley and later writers have considered as sufficiently explaining the permanent easterly winds of the low latitudes; and have stated various objections to that theory, which appear to me to have very great weight. I purpose, in the present chapter, examining more fully into the movements of the air, considered as a fluid, and as such, subject to the same laws which guide the motion of water, with this difference, that as air is a fluid, which, in comparison with water, is extremely flexile, and almost infinitely elastic, the origin of its motion is often more obscure, and the motion itself is often apparently irregular, accidental, and capricious.

The movements of water which can be seen, and which are familiar to everybody, even to the idlest of loungers who has ever passed away a weary hour leaning over the parapet of a bridge, and spitting into the river below, must commonly serve for illustrations; and I would, at the outset, call attention to the fact that a primary stream, by which term I mean a stream that has a general and absolute resultant motion in the direction of the force or

forces which first cause it, does not, as a rule, move in a steady, uniform manner. This may seem a startling paradox, contrary to universal experience, which has made the down-hill flow of water proverbial in all nations. But watch any stream for a few minutes, and the more violent, the greater the primary force is, the better. Watch the rapid current that runs through the narrow channels of a mill dam: watch a river where it rushes with accelerated velocity between contracted banks, and see that while the water, mass for mass, is flowing onwards, it is doing so in a most disturbed and irregular manner. Whirlpools, circles, eddies forming without any apparent cause, or whenever, for some reason beyond our power to appreciate, certain small volumes of the fluid hurled with greater velocity against other similar volumes, moving for the moment at a slower rate than themselves, turn round on their path in the way already described.* And such circles, such eddies are frequently, if not generally, the scene of great confusion: round them the water rages angrily, as the down-going stream meets the up-coming; the clashing currents rear their heads, and foam, and splutter, and fall back into the seething mass, and are swept onward in the general course, till, round some other slow moving portion, another similar disturbance takes place.

In singular contrast to this excitement, this irregular and whirling impetuosity, is the equable flow of a reverse stream above or below any barrier. All is peaceful, gentle, and smooth; scarcely an eddy is to be seen, or where an occasional one does intrude, it is in a languid, half-formed manner, as if conscious of breaking the established regularity. It would appear that on meeting the bank, or barrier, whatever it is, which reverses the stream, all inequality of motion is checked, and the several particles,

* *Ante*, p. 182.

as they turn back, are impressed with a velocity so uniform, that no one, hurrying on at greater speed, can strike against any other, and be thrown into a whirl.

Compare, then, this description of the motions of primary and secondary streams of water—a description, the truth of which may be verified in the nearest river or brook, in the gutter, even, on a rainy day—with the description of the westerly winds of high, the easterly winds of low latitudes. With what the winds of northern latitudes are—boisterous, irregular, veering frequently round the compass; gales, and calms, and easterly winds breaking in capriciously on their general westerly direction—we are all familiar. The still more marked, still more boisterous character of the westerly winds in the Great Southern Ocean is possibly beyond the personal knowledge of many of my readers, but is none the less a well-established fact. The Trades, on the other hand, are proverbial for their quiet steadiness: a ship may run down them for a thousand miles or more, and find scarcely any change in the force, and but little change in the direction of the wind. In the "Ladies' Sea," a gale is unheard of, a westerly wind almost as much so: and whenever, in the Trades, the wind comes round to the equatorial side of east, so as to blow from the south-east in the northern hemisphere, or from the north-east in the southern, then also it blows with unusual, though still steady strength.

It is this extreme difference between the characters of the westerly winds and the Trades, this striking correspondence to the respective motions of primary and secondary streams of water, which suggests that the view which considers the Trade Winds the primary currents of the atmosphere, may possibly be a mistaken one, and which permits us to inquire how far the details of prevalent winds in various parts of the world agree with, and

are capable of being explained by a hypothesis that the primary motion of the atmosphere is from west to east—a hypothesis which I put forward, not as an axiom or postulate, but as a possibility, which the further examination on which I now enter may prove either to be probable, or to be inconsistent with observed fact. It is in this restricted sense alone that I have here enunciated it, and that I shall allude to it throughout this chapter.

A westerly wind in the North Atlantic, when it approaches the shores of the old continent, the general lay of which—irrespective of comparatively small irregularities—is from north to south, meets with a barrier at right angles, or nearly at right angles, to its course. This barrier is not only the coast line; the land frequently hilly, often mountainous: it is also the air which rests on the land, air which is always of a nature very different from that which rests on the sea. Is it necessary to prove this difference? It is a difference of temperature, of humidity, of salts held in subtle solution; a difference of smell, and of taste, familiar even to those whose acquaintance with the sea has been limited to occasional visits to the shore in a summer holiday. Fluids, even though of the same kind, will not coalesce under different conditions. The Gulf Stream, and the United States Coast Current; the Guinea Current, and the South African or Equatorial Current, have already furnished us with clearly marked examples of this, on the grandest scale, not to speak of the Lilliputian illustrations brought forward. In addition to this, the land air is, as far as regards the air of the sea, comparatively at rest; the primary motion of it also is, indeed, towards the east; but the numerous obstacles in its way, and the highly intensified friction, check that motion: it thus, even where it is unsupported by high and impenetrable hills, offers a decided, though partial and imperfect barrier, against which the westerly wind

divides. A certain quantity of the air forces itself northwards, a south-west wind on the coasts of England, Ireland, and Norway; and it is impossible to avoid noticing the resemblance which exists in the northern part of the Atlantic Basin between the currents prevailing in the atmosphere and in the ocean. The body of air which blows from the south-west part of the coast of Norway enters into the Arctic latitudes in exactly the same way as does the water of the Gulf Stream; and, as the excess of water is driven south again, whether as the Arctic Current on the east coast of Greenland, or down Kennedy Channel, through Smith's Sound, into Baffin's Bay;* so does the excess of air find an escape in the very same places. The northerly, or north-easterly winds on the east coast of Greenland are almost continuous; and through Smith's Sound, confined by mountain ranges on both sides, they blow, not only with a constancy, but with a force that renders the inhospitable climate still more severe.† The capacity of the Arctic is limited: the space is small, and rejects with violence the air which is forced into it.

The larger part, therefore, of that air which impinges on the European coast-line turns to the south, where the tropical air, heated and charged almost to saturation with aqueous vapour, is specifically lighter. This is itself trying to move towards the east; but it is weaker than, it has not the mass or weight of, the northern side of the current, which thus presses down into it with a steady strength.

It is here that the *tendency* of air towards the equator exerts a distinct influence.‡ The difference of density may not be sufficient to give rise to a first movement; but it is sufficient to offer within the tropics a place of least resistance, such as, in a river, is offered by the sides of the

* *Ante*, p. 212.

† Dr. I. I. HAYES: The Open Polar Sea, pp. 75, 133, 193, 217, *passim*.

‡ *Ante*, chap. ii. section iii.

stream: it is sufficient to regulate the axis on which the east-going current is to divide; to prevent it from moving as *one* stream over the whole Atlantic, from the Arctic to the Antarctic circles, and to convert it actually into *two*, separated from each other by this line of least resistance, towards which, in both hemispheres, the deflections turn.

In the North Atlantic, this deflection, as it meets the outlying promontory of Cape Verde, is again deflected, forcing back the weaker stream, till the motion is entirely reversed: the wind thus blowing successively from north-west, north, north-east, and east, and becoming continually more gentle and more steady. But a portion of this atmospheric current does not turn to the west from Cape Verde, but follows closely down the line of coast, and turns with it to the east, into the Gulf of Guinea.

A very similar deflection takes place in the South Atlantic. The coast-line of Africa does not, indeed, extend so far from the equator as does the corresponding line to the north; but the barrier may be considered as prolonged, although imperfectly, to the southward, through six or seven degrees of latitude, by the different nature of the air overlying the warm water of the Natal Current; and the greater strength of the wind in the southern part of the Ocean, the greater density of the air further south, forces towards the tropics almost the whole of that which impinges on the barrier line.

The eastern side of this great stream, on approaching the Gulf of Guinea, and feeling the pressure of its northern shore, is again deflected towards the west, and blows across the entrance of the Gulf as a south-easterly wind, or nearly on a line from Cape Lopez to Cape Palmas: inside of which it turns towards the shore, forming a sort of atmospheric *backwater*, or, very frequently, a *deadwater*.

There are thus two streams of air, one from the north-east and Cape Verde, the other from the south-east, south

of Cape Palmas, blowing out to seaward. Here, again, the close analogy between these winds and the oceanic currents in the same localities, forces itself upon us: the result, also, is almost exactly the same. The two winds, converging towards each other, meet on or about the parallel of 5° N., in the neighbourhood of the meridian of 30° W.: there is between them a space over which neither has power, where, as far as they are concerned, the air is dead; where the normal westerly wind attempts to resume its sway—but feebly and fitfully, without sufficient space to develop itself, and continually interrupted by intrusive gusts and eddies from the counter-streams outside.

I have here supposed the thermal equator, the line of greatest heat, and, consequently, the line of greatest atmospheric weakness, to be in its mean position, which crosses the meridian of 20° W. in about 2° N., and, bending to the north on both sides of that meridian, passes through Whydah, in the Bight of Benin. But this axial line varies very much with the seasons. In the northern summer it moves north, nearly as far as the parallel of 8° or 10°; and in winter southwards to the equator, or, perhaps, even to 1° or 2° S. Such a change causes a corresponding change in the winds of which I have just spoken: the thermal equator is approximately the axis of the neutral ground between the two; and it is thus that this region of calms, and squalls, and heavy rain, waves backwards and forwards, not unlike the waving of a feather vane in a light, fickle breeze, and expands or contracts in a manner that may be compared to the coruscations of an Aurora Borealis.

The uniform, steady, easterly breezes, established on each side of this, move backwards and forwards with it; now towards the north, now towards the south: and with them the equatorial margins of those winds which have the original westerly direction, advance or retire. The belt of

westerly winds is thus, in each hemisphere, alternately narrowed and expanded; and whilst in summer, with a smaller volume, and with a near and ready escape towards the tropics from any increase of pressure, they blow more gently; in winter, when their volume is much greater, when the thermal equator is withdrawn to a greater distance, and their escape made more difficult, they are compelled to force their way onwards, which they do, oftentimes with devastating violence.

I have described the air over the land as being, relatively to the air over the ocean, in a state of rest. It is, however, only comparatively so: it is moving onwards towards the east, and a considerable portion of the oceanic wind follows it. Over England, France, Germany, and Russia, it pursues its course, subject to deflection from the various obstacles which oppose it. As it approaches the lofty and rugged mountains which form the physical boundary between France and Switzerland or Piedmont, it is either driven in amongst them, through narrow valleys, or over the lower passes, or is forced to the northward or southward. A great part thus escapes through the wide gap between the Eastern Pyrenees and the Maritime Alps; and blows down the western side of the Mediterranean as a northerly wind: another part escapes down the Adriatic; another down the Archipelago; sometimes as gentle breezes; sometimes, especially in winter, when the westerly winds which drive them through their several contracted openings are at their strongest, as furious and destructive storms. Similar deflections appear to take place still further to the east, wherever there are barriers of sufficient magnitude; and on the very outskirts of geographical knowledge, the Bolor Mountains, connecting the ranges of Hindoo Koosh and Thian Shan, on the western boundary of Thibet, and towering far beyond the line of perpetual snow, may be considered as the leading cause of the northerly wind, which

is said to blow almost constantly in the deserts of Bokhara.*

When the northerly winds which blow down the Mediterranean approach the coast of Africa, they are, to a considerable extent, deflected towards the west by the barrier of land and land air, against which they impinge. They thus form, or tend to form, an easterly wind in the southern part of that sea; but occasionally, or, in winter, very frequently, opposed by the westerly wind driven in through the Straits of Gibraltar, and unable to effect an escape in that direction, they are forced over the land. There are, however, certain localities where the confused meeting of atmospheric currents produces an effect similar to what, in the sea, is called a *Race:* near Cape Gata, for instance, on the coast of Spain, the northerly wind from the Balearic or Sardinian Sea, the westerly wind from the Atlantic, and the easterly wind skirting the southern shores, clash together, causing, in that neighbourhood, an almost perpetual confusion, which, in winter, most commonly amounts to a gale from some quarter or other.

The coast of Africa, from Cape Bon, westward, to the ocean, is, for the most part, high, with lofty mountains in the background; so that but little wind can penetrate into the continent on that side; but, on the east, it streams steadily in, unchecked except by the opposing nature of the land air, the relative difference of which is there at its least, or rather, owing to the continual introduction of air from the sea, is very gradual.

The northerly wind which thus enters into Africa, preserves its direction up the valley of the Nile; but further to the west, it is deflected either by a chain of mountains traversing Central Africa from shore to shore;† or, by the

* Sir ALEXANDER BURNES: Travels into Bokhara, vol. iii. pp. 14, 197.

† This mountain chain is, to a certain extent, a piece of theoretical

pressure of the corresponding current of the southern hemisphere, so that it becomes a wind from north-east, east, or even from south-east. The primary westerly wind cannot, as a rule, blow over Northern Africa, because the deflection in the Atlantic Ocean, known as the Trade wind, prevents a supply of air from being carried eastward; it does more than prevent; as it passes down the north-western coast, the friction which it exercises against the land air, rubs off, and continues to rub off, portions of it, which it carries away with it. It creates a partial vacuum, into which the air from more easterly localities flows, not, indeed, with any great force, but with a force that is still sufficient to shoot it out to seaward, and to make its peculiar heat and dryness felt at a distance of four or five hundred miles. It is, on a very large scale, the effect of the same principle relating to fluids in motion, as has been already illustrated by a description of the Atmospheric Odorator.

Such easterly winds, depending for their strength principally on the northerly winds of the Mediterranean, and, still further back, on the westerly winds of the North Atlantic, have their greatest strength and persistence at the season when these are at their strongest, that is, in the winter: it is in that season that the Harmattan blows; it was in December and January that Major Denham and Dr. Barth, on different occasions, far in the interior, in 20° N., 15° E., and 18° N., 9° E., respectively, suffered from

geography. The proofs of its existence are, 1st, The known high lands of Abyssinia; 2nd, The known mountains near the equator, on the west coast; the Camaroons and others seen stretching, peak behind peak, far into the interior; 3rd, The lofty mountains south of Bornu, seen by Major Denham, and described to him by trustworthy natives [Travels, etc. vol. i. 333, *et seq.*]; 4th, and, to my mind, as conclusive as any, the intimate and singular relationship between the mountain flora of Abyssinia and that of the Camaroons and the Peak of Fernando Po [BURTON: Abeokuta, etc. vol. ii. 39].

the violence and cold of continuous north-easterly gales,* and it was in the end of December that Captain Burton, in his ascent of the Camaroons, found a strong wind from the north-east blowing persistently at altitudes varying between 7,000 and 13,000 feet; † the pressure from the interior being sufficient to force the air up the mountain slopes, even to that great elevation. The escape on that side, however, is at times insufficient for the quantity of air which is so constantly driven in from the northward. In the late summer, or early autumn, when the southern limit of the Trade wind in the Atlantic has backed from the line as far as the tenth or even the fifteenth parallel, and westerly winds blow frequently on the coast, the air is not only no longer drawn away from the land, but is driven inwards. At this season fitful gusts and squalls, sometimes even lasting breezes from the west are experienced in the southern part of the central basin; and the air over the land, being in excess of that which the space admits, and having its elastic force greatly increased by the excessive heat of the desert, thrusts itself violently out at occasional and irregular intervals, when it is felt as an exceptionally strong hot wind at Madeira and the Canary Islands, or over the whole extent of the Mediterranean as the Scirocco.

In the basin of the South Atlantic there is a corresponding deflection on the extreme east, caused by the mountain chain which bounds it on that side. That part of the westerly wind which forces itself on to the land, turns from this towards the north, and again from the equatorial chain toward the west, and blows for most of the year over the greater part of South Africa as a south-easterly wind; its

* DENHAM, CLAPPERTON, and OUDNEY: Travels and Discoveries in Northern and Central Africa, 1828, vol. i. pp. 135, 167.—BARTH: North and Central Africa, vol. i. pp. 577, 578.

† BURTON: Abeokuta, etc., vol. ii. *passim*.

easting being increased, as in the northern division of the continent, by the air being continually dragged away from the west coast by the friction of the southerly wind of the ocean. During the summer months, when westerly winds are frequent on the northern parts of the shore, there is no longer the same tendency to form a vacuum there, nor a call for air from the interior to fill it. On the contrary, the pressure from the westward commonly bears back the deflection from the eastward, and the oceanic air is forced over the land as a moist wind, charged almost to saturation with vapour, which it throws down in deluging showers.

In the eastern part of the basins of the Pacific, the deflections of the westerly wind are, in their nature, almost exactly identical with those just described in the Atlantic. In both the northern and southern hemispheres, the deflection which takes place towards the thermal equator, between the parallels of 30° and 40°, forms the north-easterly and south-easterly winds known as the Trades. According as, with the changing seasons, this line of greatest heat moves north or south, so do the axes of the bands of westerly winds, — the parallels on which they divide, — also move north or south; but whatever may be the season, and the consequent position of these parallels, on the equatorial side of them, the winds prevail from the polar side of west; and on the polar side of them, the prevailing winds are from the equatorial side of west. Thus, on the coast north of Vancouver's Island, the winds prevail from the south-west all through the year, and on the coast of Old California from the north-west; but between these, on the coast of Oregon and New California, they prevail from the south-west in winter, and from the north-west in summer: the duration of each on different parts of the coast varying with the latitude, according as the axial line is for a longer or shorter time

to the southward or northward of any specified locality. On the coast of South America a similar alternation takes place—the changes on the coast of Chili, from south-west winds and dry, clear weather, to north-west winds and rain, following very closely the march of the thermal equator; whilst in Patagonia, further to the southward, the north-west winds and heavy rain continue without intermission during the whole year. Between the Trades, and having the line of greatest heat for the time being as an axial line, there is, as in the Atlantic, a neutral region where neither Trade blows, where the primary westerly wind seeks to regain its sway, without, in the limited space, being able to do more than cause frequent westerly squalls. The mean position of the thermal equator cuts the American shore in latitude 10° N., so that the whole of this region is almost always to the north of the line, though it extends further to the north, and is broader in the northern summer than at any other season of the year. It is then that westerly winds are most common on the coast of Central America—winds which very frequently force themselves across the low-lying districts of the Isthmus of Panama, and form the rain-bringing Vendabales of Carthagena, and the adjoining coast.

At all seasons of the year, however, there is a branch of the first deflection of the primary westerly wind, which does not turn back towards the west as the Trade, but adheres to the coast line, and blows along the eastern boundary of this neutral district, changing in direction from north-west to south-east, according as the season of the year gives more power to the current of air from the north or from the south,—according as the axial line of greatest heat is nearer to or further from the equator, according as it is the northern winter or summer,—and forming those alternating winds which are sometimes spoken of as the Monsoons of the west coast of Mexico.

A westerly wind blowing over the continent of North America and over the North Atlantic for any length of time must necessarily cause, or tend to cause, a vacuum in the western part of the basin. The lofty mountain range which bounds it, is an absolute barrier against the ingress of air from the Pacific; and, as we have just seen, the atmospheric current on the Pacific side, which impinges on it, is deflected towards the north or south. Far above the surface of the earth, the prevailing westerly wind sweeps more or less uninterruptedly past the rugged and snow-clad peaks, unable in any great volume to penetrate to the sheltered plains under their lee. A tendency towards a vacuum is, therefore, felt in those latitudes in which, in the Atlantic, the westerly winds are most constant; and to fill this, the adjoining air is drawn in. From the Gulf of Mexico on the south, from the Arctic on the north, there is a steady stream towards the weak point. The Trade wind pours a continuous supply into the Gulf of Mexico from the eastward; and this, as soon as it comes within the influence of the threatened vacuum, turns towards it, blowing successively from the south-east and from the south, gradually falling into and becoming a constituent portion of the primary westerly wind which carries it away towards the Atlantic and the shores of Europe; whilst on the north, the air from the Arctic regions, itself having a motion towards the east, and supplied by the northerly deflection in the Pacific, is drawn down the eastern side of the mountains, a broad belt of northerly wind, till, as it gets into lower latitudes, it too is swept away by the great primary stream. To a smaller extent there is a similar indraught towards the axial line of the westerly winds on the eastern shore of North America: the aërial current, moving over the sea with a greater velocity than it does over the land, tends to form a partial vacuum near the coast line, to supply which there is a call on the air

from the south as well as from the north; and in both localities, both near the coast and further west near the mountain range, there is in winter—when the westerly winds are more violent, when the tendency to form a vacuum is more decided, and the indraught is consequently stronger—a frequent rush of the dense air of the north, which being once set in motion sweeps to the southward with great force, a northerly gale either on the seaboard of the Atlantic, or over the plains of the Mississippi Valley, and in the Gulf of Mexico: whilst at the same season, the strong westerly wind of the Pacific occasionally forces itself through very narrow and imperfect openings in the mountains, in gusts whose sudden and unprepared-for cold is often as fatal on land as their violence is destructive at sea.

Over the continent of South America, the result of a prevalent westerly wind in the mid-temperate latitudes is very similar to what it is in the United States. The mountains of Brazil, running from north-east to south-west, in lines nearly parallel to the coast and to each other, give the Trade wind, as it approaches them, a direct deflection towards the south-west, so that a north-easterly wind blows for the greater part of the year, whether on the coast, or up the different valleys of the interior. This wind is steadiest in the summer, when the southerly position of the thermal equator, and the retreat of the axial line of the westerly winds towards the south, cause by far the larger portion of the air which constitutes the South-East Trade to strike against the coast of Brazil, to the southward of Cape St. Roque; but, in winter, when this Trade extends farthest towards the north, a great portion of it is pressed, by the easterly projection of the coast line, still further to the north-west, to mingle with the North-East Trade, and to supply the indraught from the Gulf of Mexico: this, as it passes on, drags with it the air from the southward,

exactly as the air is dragged up the tube of the Atmospheric Odorator, and causes a southerly wind to blow commonly, though not very steadily, for a considerable distance down the coast. But the double attraction—that towards the south, this towards the north, while it causes frequent squalls from north, east, or south—causes also frequent calms. These, as well as the general easterly and southerly winds which strike nearly at right angles on the coast line and the mountain chain, occasion that copious precipitation which takes place along the whole coast between Rio de Janeiro and Cape St. Roque, in the season from April to August.* Inland, to the west of the mountains of the Atlantic seaboard, as also to the southward, it is the north-east wind of summer which brings the rain, whether to the upper basin of the Saõ Francisco, and of the Paraguay, in September, October, and November, or to the Chaco and the Pampas in November, December, and January.

At the same time of the year, the North-East Trade, extending to its southern limit, blows home to the northern coast of South America; and a part of it, forcing its way over the land, reaches across the Llanos, to the great mountain chain of the west; being deflected by it, it turns down the Amazon, a confused westerly wind, carrying with it not only its own vapour, but also the vapour collected at the foot of the Andes, during many months of easterly breezes; and, amid violent squalls and fearful storms of thunder and lightning, produces those heavy rains in the upper part of the river which continue from February to June, and swell its waters to a height forty feet above the level of the dry season.†

* DAMPIER: Voyages, etc., vol. iii. p. 86.—ADMIRALTY: Wind and Current Charts of the Atlantic, 1868.

† BATES: Naturalist on the Amazons, vol. ii. pp. 25, 220.—A. R. WALLACE: Travels on the Amazon and Rio Negro, p. 418.

The air in both the North and South Atlantic, subject to this hypothetical primary movement towards the east, is thus forced by the several obstructions offered to that movement, and, in accordance with the recognised principles of the motion of fluids, to circulate in a general way round a central space, in which the air partakes, for the most part, of the movement towards the east, but irregularly, interrupted by contrary streams and eddies, which curl into it from the different atmospheric currents circling round it. It is, in fact, a species of atmospheric Sargasso Sea, where calms are very common, and squalls from every possible quarter frequent, but amongst which, on the whole, the west wind predominates. It is this space which, in the North Atlantic, is frequently spoken of as the Horse Latitudes, and in the South Atlantic has been designated the Calms of Capricorn.

Across the vast extent of the Pacific, the Trade winds, formed, as described, by the deflection from the west coast of America, blow but feebly; the distance is so great that the reverse motion is frequently overpowered, especially in summer, when the volume of the primary current in the respective hemisphere is at its least. It is then that the normal westerly wind intervenes. This is more particularly the case in the South Pacific Ocean, where the distance is greatest, and the interruptions, from islands, unceasing. Against these islands, for the most part mountainous, the atmospheric current grinds, losing a portion of its velocity by the friction: round them it circles and eddies, until swept on its course, but always with loss of velocity; and thus it happens that, in the western half of the South Pacific, the Trade in summer is almost entirely supplanted by the general west wind, which blows boisterously and in fitful squalls as it struggles against the faint remains of the wind from the east.

In the North Pacific, the Trade wind is, in winter,

reduced to its narrowest limits, and the west wind blows freshly across the ocean, often as low as the twentieth parallel. But in the extreme west of the basin, this westerly wind blowing from the high mountains which form its boundary, leaves, or rather continually tends to leave, a vacuum, to fill which a portion of the current of air turns down from the north. There is a similar tendency to form a vacuum on the east coast of China, where the sea air is drawn, with increased velocity, away from the land; and there is, therefore, a similar indraught from the north. Such a northerly wind would be almost identical in character with the northerly wind which, during the winter, prevails over and along the eastern coast of the United States: but the peculiar island barrier off the coast of China —a barrier which, lofty and rugged, extends, though in a scattered and irregular manner, from the peninsula of Corea to the equator—confines it within narrower bounds, deflects it more decidedly to the southward, and gives to it, as the Northerly Monsoon of the China Seas, a strength and persistence far beyond what its North Atlantic counterpart has, whether in the Gulf of Mexico, or on the coast of Georgia, or of Florida.

In summer, when the axis of the westerly wind retreats from the equator towards the north, the air which has to supply the continual tendency towards a vacuum is drawn in from the south, as is the case also on the western side of the Basin of the North Atlantic; but the island barrier again, as in winter, produces an important modification of this southerly wind in the Pacific. As the west wind passes across the northern opening of the narrow seas, as across the end of a tube, it offers another instance of the natural application of the principle of the Atmospheric Odorator; it draws the air out of the narrow channel, and a continuous stream from the south, which, following the trend of the coast-line, becomes from south-west, is the

necessary consequence, a wind which, as the Southerly Monsoon, has thus a constancy and strength far greater than the corresponding summer wind in the southern States of North America.

In the South Indian Ocean, that part of the westerly wind which impinges on the coast of Australia is deflected to the north, and again, by the continuous influx of air, to the west, forming the South-East Trade. Further east, another part of it blowing over the southern part of the Continent as a south-west wind, is similarly deflected towards the north by the Australian Alps and the other mountain-ranges of the far east, and forms the south-easterly wind which seems to blow over Central Australia during, at any rate, a great part of the year.* In summer, when the westerly winds are at their farthest from the equator, the portion of them to the north of Cape Leeuwin is comparatively small, and the supply to the Trade wind scanty. At this season, the Trade is feeble, and is so reduced in breadth, that it does not reach beyond the parallel of 10° S., north of which the westerly wind blows in an interrupted and fitful manner; but in winter, the Trade wind, with increased strength, extends almost to the line, and, being derived from strong and steady westerly winds, blows freshly across the whole sea, to the coast of Madagascar, against which it impinges and divides, some of it turning south, but the greater portion turning north, and blowing across the Line, a fresh breeze from between S. and S.E., and drawing after it the air out of the Mozambique Channel, thus forming the South-West Monsoon of that locality.

In the North Indian Ocean we meet with geographical peculiarities, and attendant anemological phenomena which have no exact parallel in any other part of the world. Bounded on the north by a chain of lofty mountains, run-

* *Ante*, p. 85.

ning approximately along a parallel of latitude, and but a small distance beyond the tropic, the possibility of a wind similar to the North-East Trade of other basins is shut out. Owing to the physical nature of a great part of the land, to the arid deserts, which are excessively hot in summer, and are often subject to comparatively severe cold in winter, the thermal equator experiences very wide changes of position; and whilst in the summer months it runs far to the north, almost at the foot of the mountains, across Arabia and Persia, passing through perhaps the hottest parts of the inhabited world, it recedes, in winter, almost to the equator. The range of this line of greatest heat thus extends across the whole width of the North Indian Ocean, from north to south; and its relative position in the varying seasons, even in the different months, exercises a very marked influence on the deflections of the primary atmospheric current from the west. In summer the westerly wind prevails over the whole of the basin; in the southern part, from near the equator to the parallel of 10° N., it blows from almost due west; on the west coast of Ceylon it is deflected towards the north or south, according as the position is towards the north or south end of the island; through the Gulf of Manaar it blows from the south-west; past Point de Galle, from the north-west. A somewhat similar difference is found on the mainland; past Cape Comorin it blows from the west; further north, as far as the 12th or 13th parallel, it is north-westerly, but beyond that it turns to the weakness of the thermal equator, and is south-westerly.

In this change of direction corresponding to change of latitude, there is a striking resemblance to that which has been noticed on the west coast of South America, where, from Cape Horn northwards, to about the 40th parallel, the westerly winds are deflected towards the south, but nearer the tropic, rather towards the north. The penin-

sula of Hindostan, although in a different hemisphere, is, during the summer, on the same side of the line of greatest heat, and the changes in the deflections of the atmospheric currents are thus very similar.

The westerly wind, blowing away from the African coast, causes there the same tendency towards a vacuum that is similarly caused on the east coasts of North or South America, or of China, and the effect produced is the same; the air from the south pours in a ready supply, offered freely by the fresh South-East Trade of the southern basin, which is thus drawn up, not only to the equator, but into the northern hemisphere, where it enters into the new circulation. On the east side of the peninsula of Hindostan a similar tendency to a vacuum is caused by the westerly wind blowing away from the land, across the Sea of Bengal, and there is, to supply it, a similar indraught from the southward, which, near the coast, forms a wind along shore, and more to seaward, a south-westerly wind, which when it strikes the opposite coast of Burmah is deflected by it, and the mountains behind, towards the north, becoming a wind from S.S.W., or even South.

But in the winter, circumstances are very different. The line of greatest heat is then to the south instead of the north of the North Indian Ocean, and winds obstructed in their course towards the east—whether by the peninsula of Hindostan, by the mountains of Beloochistan, by the Himalaya, and by the Western Ghauts, or still further east, by the mountains of Burmah and Malacca—turn to the south where the line of least resistance is then situated, whilst the air to supply the vacuum constantly tending to form on the east coast, whether of Africa or of Hindostan, is drawn from the north, and following the trend of the coast, which is the same in both instances, forms a north-easterly wind. This north-easterly direction is thus

strongly marked in the western parts of both the seas of Arabia and Bengal, but on their eastern sides, the wind blows from the north-west, and in the lower latitudes of the basin, from almost due west.

It thus appears that, in every part of the world, the direction of the prevailing winds is such as would be produced by a general primary atmospheric movement from west to east, differently deflected, or drawn in, in different places and under different circumstances, but always in accordance with the recognised principles of the motion of fluids. But, though these local winds might possibly be such deflections of a general wind from the west, it by no means follows that they are; and, in fact, they have been explained in a very different manner, and their origin traced to widely different sources, by various writers, whose names and opinions carry great weight. These explanations, for the most part corollaries to Hadley's theory of the Trade Winds, are all founded on the assumption that the one great cause of wind is the unequal expansion of air by different degrees of heat.

As I have already shown that there is grave reason to doubt this, and that such an assumption is not warranted by observed facts, I shall not at present especially revert to it, but will examine rather into some distinctive points of detail, physical or geographical; points on which, indeed, the explanation of the local peculiarities is often entirely founded.

Professor Dove has quite recently published two small works,* in which he traces the Scirocco of the Mediterranean to the South-West Upper Current, returning from the tropics, above the Trade wind, and descending to the earth in the latitudes of the Mediterranean, warm with

* H. W. Dove: Ueber Eiszeit, Föhn und Scirocco, 1867.—Der Schweizer Fön, 1868.

tropical heat, and moist with tropical vapour.* It would be unreasonable to doubt that the winter south winds in Switzerland, to the examination of which Professor Dove confines himself, are very frequently deflections towards the north, of the west or south-west wind of the southern parts of the Mediterranean; and that such winds do occasionally blow in the mountain districts with great force, and cause very great damage by the violent floods resulting, not only from the heavy rains which accompany them, but also from the sudden and unseasonable melting of the snow by the warmth brought from the sea-level of lower latitudes. But it is impossible to admit that such winds are properly called by the name Scirocco; and a false local, or rather provincial usage, seems to have led the distinguished meteorologist into error: Scirocco is a word of Arab derivation, and a Scirocco is a wind known to the country of the Arabs. In Arabia, in Egypt, along the whole northern coast of Africa, it is commonly experienced, a south or south-east wind. In Sicily it is a south-east wind, and is particularly described by Admiral Smyth as first striking the east shore, and blowing over the land to Palermo. In Malta, it is a south-east wind; and the bay at the south-east end of the island, open to the south-east, and which thus receives the full and first force of a south-east wind, is Marsa Scirocco.

Neither is the Scirocco a peculiarly winter wind; it does, indeed, occasionally blow in winter, but it blows also in summer, and still more often in spring or autumn. Professor Dove considers that the warmth which it carries with it is the warmth of the Caribbean Sea; but, if he had ever experienced the discomfort of the Scirocco as it is felt at Malta, he would have known, or have been able to imagine, that the air of a Scirocco is widely different in its nature from the air of the West Indian Islands. Amongs

* *Ante*, p. 108.

these the air has a temperature of from 75° to 85° F., and is moist almost to saturation. The air of the Scirocco has a temperature of 90° or 95° F., and though containing some moisture, is sufficiently dry to split unseasoned wood, or to snap harp-strings; whilst, on the mainland, before it has crossed any of the water of the Mediterranean, its dryness is, as a rule, even still greater.

But that air from the desert should have vapour—and often an absolutely large quantity of vapour—mingled with it, need not cause astonishment. The air has not been always over the desert. Most of it has blown there from the Mediterranean itself, perhaps almost saturated at the temperature of summer; much of it has blown there from the Gulf of Guinea, and some also from the Red Sea, almost saturated at still higher temperatures; and a great part of the vapour it contains when it enters the desert, remains in it and comes out with it: some, indeed, in its superheated condition, it has dispersed; we cannot say how much, but it leaves very little behind; the rainfall in the wide wastes of Africa is extremely scanty. A similar presence of moisture has been observed in the case of the Hot Winds of Australia, which have been traced to their origin—almost, in some instances, to the very locality where they acquire their peculiar heat.* These winds thus certainly blow off the desert; a desert not indeed so vast as that of North Africa, but still vast and arid enough to permit of a legitimate comparison: and when we find that the effects of a Hot Wind, known to come off the deserts of Australia, are identical in the most peculiar points with those of a Scirocco; that both blight fruit-trees, extract the colour from grapes, prevent wine fining or meat curing; that both present at the same time the very opposite properties of humidity and dryness; that both deposit moisture, and yet cause a rapid evaporation;

* STUART: Journals, etc. pp. xiii. 473.

that both produce the same indescribable feeling of discomfort—we are led fairly to the conclusion that winds so peculiar, so distinct from all other winds on the face of the earth, and yet so closely alike in their distinguishing features, must be alike also in their origin; and that that origin is the burning desert.

Great, and it appears to me, undue stress, has been laid by Professor Dove, Captain Maury, and many others, on the results of the microscopic observations made by Professor Ehrenberg, on various small packets of red sand let fall by the south wind on the coast of France and in Switzerland. These observations showed that the sand contained a large proportion of very minute shells of a fresh-water type; and that, of these, some two or three were of species which have been found in South America, in the basin of the Orinoco, whilst none could be recognised as belonging to any part of the Old World. It has been said that they cannot possibly be of African origin, because the sand of the Sahara is a *marine* formation. There is no doubt that the Sahara was, at no very distant geological epoch, the bed of the sea; but there appears also reason to believe that at a still later period, the northern part of it, at least, was a region of fresh-water lakes, and it is quite certain that many fossil shells have been found there, which are specifically identical with others found by Captain Spratt in fresh-water deposits near the Black Sea.* And putting on one side the impossibility, in the present state of our geographical and geological knowledge, of determining with certainty the non-existence, in the wide area of North Africa and Arabia, of a few species of microscopic shells, it is worth calling attention to the fact that Professor Ehrenberg's observations on red dust, collected near the Cape Verde, or Canary Islands, and off the adjacent West Coast of Africa, gave almost exactly the same results, and

* H. B. TRISTRAM: The Great Sahara, p. 370.

furnish as strong an argument in favour of the South American origin of that also;* and this Captain Maury gladly accepts as one of the most convincing and satisfactory proofs that the air of the South-East Trade does, on ascending, cross over into the northern hemisphere as an upper current, and continue its course to the northward, in the manner I described when explaining his peculiar theory of the atmospheric circulation.† But the observations of Professor Piazzi Smyth, on the Peak of Teneriffe,—in the course of which he noticed that the dust haze, which almost constantly filled the atmosphere, and rendered the view indistinct, was in the stratum of air moving from the eastward; that high overhead the air was clear, and that when the westerly wind descended to their level, all traces of the dust haze in their immediate neighbourhood vanished,‡—seem to offer conclusive evidence that, notwithstanding the microscopic observations and the deductions from them, the dust haze of the West Coast of Africa is, as the natural sense of navigators would suggest, a dust from the interior of Africa. And it is perhaps worth remarking, that Professor Smyth was annoyed by this dust in July and August; that I myself have experienced it, to the north-west of the Cape Verde Islands, in May; that Mr. Darwin found it there in January; and that some of that of which Professor Dove speaks fell in Switzerland in October. The Llanos of the Orinoco were certainly never in a state of arid dust at all these widely different seasons.§

* DARWIN: Journ. of Res. p. 5.

† *Ante*, p. 109.—MAURY: Phys. Geog. of the Sea, § 324.

‡ Teneriffe, p. 127, and *passim*.

§ It will be, perhaps, interesting to add that *red snow* has been frequently found to owe its colour entirely to local causes, as, for instance, in Switzerland, to the presence, in vast quantities, of an extremely minute species of algæ (Protococcus Nivalis); and in the Arctic to the brick-red droppings of millions of little auks.—Peaks, Passes, and Glaciers, 2nd Series, vol. ii. p. 369.—Seasons with the Sea Horses. p. 93.

I believe therefore that the opinion that the red dust and blood rain is of South American origin, is based on a too hasty generalization from very imperfect and isolated data; and is as contrary to the sense of thousands, who, like myself, have seen it borne on the east wind of the North Atlantic, as it is to the evidence of Professor Smyth, who found the upper west wind always clear of it. And further, that Professor Dove's opinion that the Scirocco is a deflection of the south-westerly wind of the Atlantic is founded on an entire misconception of the actual nature of the Scirocco; and that though the south-west wind of the Atlantic may turn northwards in the Mediterranean, and be the Föhn of Switzerland, the Föhn—a name directly derived from the Latin *Favonius*, a soft south-west wind—is totally distinct from the genuine Scirocco.

But although I think it highly probable that the Föhn of Switzerland is frequently a deflection of the south-west wind of the Atlantic and the southern parts of the Mediterranean, I cannot by any means admit the reasoning of Professor Dove and others, who attribute its warmth and moisture to the warmth and moisture of the air of the Caribbean Sea. According to this, the air ascends, travels over the intervening space, and descends in the Sardinian Sea, without undergoing any material change in its several qualities of warmth and moisture. It is difficult to understand how such an extraordinary idea can ever have been seriously entertained. The expansion of air, as it ascends, chills it enormously, and this chilling, as already explained at considerable length, causes it to precipitate its moisture copiously. In addition to this, air, when lifted up above the dense screen of aqueous vapour near the surface of the earth, radiates into space with wonderful rapidity,* and thus experiences a diminution of temperature far greater than what is due even to the violent expansion to which it has been

* TYNDALL: Heat, etc., §§ 488, 491, p. 404.

subjected. All observation shows that the temperature of the air, in the higher regions of the atmosphere, is very low. Captain Burton found a temperature of from 40° to 45° F. on the top of the Camaroons, an altitude of 13,000 feet, when at the sea level the thermometer showed 85° F., and the west wind blowing high above his head was, it may be presumed, still colder. On the Peak of Teneriffe, the west wind has been commonly found to be about 35° F., or from that down to freezing point; and instances without number in other parts of the world show that the rule is general, and that at still higher elevations the temperature is still lower. But it is not supposed that the air of the upper current pursues its way at a uniform level; it rises and falls through heights of several thousand feet,* and must thus, in the course of a long passage, be frequently subjected to degrees of temperature far below even 32° F.

Now, if air of a temperature of 85° F., saturated with vapour, be shot into the upper regions, and chilled whether by expansion or by radiation to 32° F., it cannot possibly hold the same amount of vapour as before. At a height of 15,000 feet, the elastic force of the air is, in round numbers, only half of what it is at the surface; and any mass of air is therefore at that height expanded to twice its original volume. With it the aqueous vapour it contains is also expanded to twice its original volume. Aqueous vapour, at a temperature of 85° F., has an elastic force equivalent to 1·17 inches of mercury, and therefore, when expanded in the ratio just mentioned, has a force of ·585 inches; but the force of aqueous vapour, at a temperature of 32° F., is only ·2 inches: the quantity of vapour corresponding to the difference between these pressures must therefore be precipitated. At any rate, the air of the upper current, at a temperature of 32° F., cannot hold

* SMYTH: Teneriffe, p. 170.

in itself more vapour than what is denoted by a pressure of ·2 inches of mercury, which, when the air, by descending, is compressed to its original volume would become ·4 inches. This, then, represents the maximum quantity of vapour which air, descending from such an upper current, can possibly contain, and is much, very much more than, in all probability, it ever would contain; but if this was the force of the vapour in a warm wind of the Mediterranean, a wind which has a temperature of 60°, 70°, or at times even 75° F.—that wind, with a dew point of only 52° F., would be, at the lowest of these temperatures, noticeably dry, and at the highest would shrivel up everything with which it came in contact. Such is far from being the character of the wind under consideration: it is a wind which, whatever may be its temperature, is moist almost to saturation: it is a wind that throws down perfect deluges of rain, not only in Switzerland, but in Italy, and even in Sicily.* The quantity of vapour the air contains is not only relatively but absolutely great, which tells of a high temperature as certainly as any thermometric record can do; and it is difficult to conceive that air exposed during a passage of many thousand miles in the upper current to the excessive loss by radiation, spoken of by Professor Tyndall, should be found on its descent, and on compression to its original volume, to be only 10° or 15° colder than when it first ascended from the Caribbean Sea. This, however, might perhaps be so. The loss by radiation has not yet been exactly ascertained and reduced to figures; but the relative force of aqueous vapour, and the quantity which a volume of air is capable of containing, at different temperatures, has been very accurately determined; and it is quite certain that air which had been long dried by extreme cold in the upper regions could not precipitate those quantities of rain which, in the Mediterranean,

* Dove: Law of Storms, p. 234.

so generally accompany the winter gales from the south-west.

Captain Maury has committed the same mistake in attributing the prevailing west and south-west winds of the United States to the upper current from the tropical region of the Pacific descending there with its warmth and moisture, and precipitating sufficient of the latter to give rise to, and continually supply, such rivers as the Mississippi, the Missouri, the St. Lawrence, and the countless smaller, though still important, streams.* He has omitted from his calculation the drying influence, not so much of the mountains as of the upper regions of the atmosphere; and has—as European meteorologists have also done—supposed that a body of air which ascends warm and moist will descend the same. I have just shown that it will not, and that it cannot. About the temperature to which air passing over the Rocky Mountains is exposed, there is no doubt. We know that on them the snow lies thick for many months; in places during the whole year. High above the snow-clad peaks the westerly wind must pass through a temperature far, very far below the freezing point; and if it descended to the earth, would be not only a wind exceedingly cold, but also, and of necessity, a wind exceedingly dry. A soft, warm, moist south-west wind, blowing over the northern States of America cannot possibly have passed over the mountains. But over the greater part of the States, the south-west is the prevailing wind; Mr. Blodget says it is usually humid. "It is the soft, pleasant, peculiarly American wind, with a finely variable force. Rains are frequent with it, and often form in its volume in the warmer months, as thunder showers."† This soft, moist wind marks its own course, and traces on the face of the country its own line from the sea, as clearly and unmistakably as could be done by any self-registering

* Phys. Geog. of the Sea, § 276. † Clim. of the U.S. p. 136.

instrument. The rainfall, greatest near the southern shores, diminishing towards the north and west, describes a series of nearly parallel curves, crossing the continent from the Gulf of Mexico to the shores of the Atlantic. This, then, must be the direction which the wind has followed: the sea air, coming over the land, parts with its moisture gradually, but most freely at the first check: the coast which has the greatest rainfall, and from which the rain-fall regularly diminishes towards the interior, is necessarily the coast across which the rain-bearing winds enter the country: and the registers of rain-falls, as exhibited either in figures, or in Mr. Blodget's maps of the different seasons, afford sufficient proof that the winds, which on a former page I described as blowing through the States successively from the south-east, south, south-west, and west, are, in reality as well as apparently, *one* continuous stream of air flowing without serious interruption from the Gulf of Mexico.

This is again further illustrated by the curious fact already mentioned,*—that the Alleghany Mountains exercise very trifling influence on the climate of North America. Notwithstanding the gentleness of their slopes as compared with those of many other mountains, they are so lofty that they might very well be expected to have permanent weather and lee sides, the climates of which would be very different. This is not so: they have no weather or lee side; but at their southern extremity stand end on to the direction of the great aërial current from the south, which thus glides quietly along both sides, as the water of a river slips past the sides of a ship at anchor in the stream.

The violent winter storms from the north-west must, however, be considered as coming out of the cold regions of the north. The motive force which produces the westerly winds of the Atlantic seaboard,—and whatever that force may be, the westerly winds themselves are

* *Ante*, p. 10.

observed facts,—causes them occasionally to move faster than the air streaming in from the south can supply. The west wind overhead, continually blowing, drags along and upwards that nearer the surface; there is—to a certain extent—the same action as in the oft-mentioned Odorator; and below, in the neighbourhood of the mountains, there is a tendency towards a vacuum; which, generally to be traced only in the moderate effects it produces, is at times extremely marked, showing itself on the barometer in the same way that a few strokes of the air-pump would show themselves on a barometer inside the receiver. Along the whole line of the States, from north to south, west of the Mississippi, the elastic force of the air is lessened, and the barometer falls, sometimes nearly an inch.* Into this comparative vacuum the adjoining air rushes with great force; on its respective borders, the storm commences from the north, from the south, or from the east; but the greater volume and density of the north wind give it a momentum superior to that of the others; and the genial air from the south is borne back by the icy blast which reaches the whole length of the continent, across the Gulf of Mexico, and makes itself felt even on the opposite coasts of South America, or occasionally on the other side of the isthmus; whilst a large part of the intruding volume, deflected somewhat to the eastward, perhaps by the mountain line, perhaps by the continued pull of the westerly winds, passes over the eastern States, and so to the Atlantic seaboard. It is thus a violent storm over the whole of North America; a severe westerly gale in the north-eastern States, and known further south and in the Gulf of Mexico as a NORTHER; but everywhere distinguished not only by the strength of the wind, but by the biting cold which accompanies it.

* ESPY: 2nd and 3rd Report on Meteorology, p. 5, and *passim*.—ROBERT RUSSELL: North America, p. 320.

To this origin of Northers, it has been objected that the cold is frequently found in Texas to precede, and to be more severe than that experienced further to the north. It is argued that they must, therefore, be extensions of West Indian Hurricanes ;* losing sight of the two very obvious facts that a body of air driven in from the West Indies cannot be icy cold, and that Northers scarcely ever blow during the Hurricane Months.† On the other hand, the Rio Grande and the Gila are, about the middle of their respective courses, separated by a plateau, now known as the Madre Plateau, over which the continent can be crossed without exceeding a height of 4,000 feet ;‡ and air pressed onwards from the west may, in exceptional cases, be driven through this, the broadest and lowest of the openings in the mountain system of North America, as well as through others of less importance, dragging with it the air from still more elevated districts, and bringing on to the plains of Texas the intense cold of even the snowy peaks.

Storms of a nature exactly similar to the Northers are of common occurrence also in South America, although, in consequence of the continent and the mountain range not extending so far towards the pole, as in the northern hemisphere, they are neither so violent nor so intensely cold. The cold is, nevertheless, a marked feature, and has been frequently noticed by travellers as suddenly accompanying a rare south wind, even in the neighbourhood of the equator, on the Amazon and its tributaries.§ So far to the north their strength is only moderate; but to

* W. C. REDFIELD: On Three several Hurricanes of the Atlantic, and their relations to the Northers of Mexico and Central America. Newhaven, 1846, p. 113.

† *Ante*, pp. 26, 28 ; see also, *post*, chap. vii.

‡ FRŒBEL: Seven Years' Travel, etc. p. 559.—W. A. BELL: New Tracks in North America, vol. i. p. xxvii.

§ BATES: *Op. cit.* vol. ii. p. 223.—CHANDLESS: in Journ. of the Roy. Geog. Soc. vol. xxxvi. p. 91.

the south of the La Plata, where they spread out to the eastward, they blow with great fury; and, as Pamperos are well known on the Atlantic coast, whilst still further south, the southerly gales off Cape Horn, though not so numerous as those from the west, are described as even still more violent. We have no exact information which enables us to connect the cold southerly winds of the different localities,—to put together the separate links of the chain,—with the same certainty that we can the westerly and northerly winds of North America; but the circumstances resemble each other so closely: a prevailing westerly wind in mid-temperate latitudes, blowing away from a very lofty and impenetrable chain of mountains; a constant indraught from the tropics, and occasional interruptions to the ordinary course of the wind by a westerly gale of unusual strength and of intense cold; by a polar wind which, in different parts of the country, wherever it is felt, is also exceedingly cold: it is scarcely possible to doubt that the cause of both is the same, and that the southerly winds which, at times, reach even to the equator, and which frequently in Paraguay suddenly lower the thermometer by 20° or 25°,* are the extensions of those gusts from the southward, which, at Cape Horn, are furious southerly gales, and, off the mouth of the La Plata, are violent and dangerous south-westerly storms, in exactly the same way that the Northers of the Gulf of Mexico and the westerly winter gales of the New England States are branches of the same rush, towards the south, of Arctic air, consequent on the dragging away to the east of the air resting over the continent, and on the formation of a comparative vacuum, the rarefaction in which has been, in many instances, very satisfactorily measured.

The tracing the winds of North America to their origin

* DU GRATY: La République du Paraguay, p. 240.—PAGE: La Plata, etc. pp. 151, 162, 239, *passim*.

in the Gulf of Mexico and the Arctic, by actual and oft-repeated observation, shows very conclusively that there is there no wholesale descent of air—no continuous descending current—such as Captain Maury has supposed; that the westerly winds, which certainly prevail near the surface, are not winds from the upper regions, and that the westing is therefore not that due to the rotation of the earth, according to Hadley's theory.

Again, the course of the Scirocco from south-east to north-west, a course which it undoubtedly pursues—and which Professor Dove shows, at great length, from theoretical considerations, it cannot pursue—is a very conclusive proof that those theoretical considerations are founded on a false basis. Professor Dove argues that a wind from the desert of Africa must, on going north, pass away to the east, a south-west wind which may be felt in Asia Minor, in Syria, or still further to the east, but can not be a south-east wind parching Malta, Sicily, and Italy. "Air," he says, "which ascends over Africa, strikes Asia, not Europe; the cradle of our southerly winds is, therefore, not the Sahara, but the West Indies."* I have just shown that, on the contrary, the winds from the deserts of Africa and Arabia do come to Europe; and, by doing so, they furnish additional evidence of the fact already dwelt on, that the differences of the surface velocity of rotation, due to the differences in length of the degrees of longitude on different parallels of latitude, do not very materially affect the direction of the wind.

It is, however, to the Monsoons of the Indian Ocean that the theorists of this school refer, as offering, after the Trade winds, the most conclusive proof of every detail. The indraught produced by heat—the veering due to the rotation, both for northerly and southerly winds, is said to be more clearly exemplified there than anywhere else in

* Ueber Eiszeit, u.s.w., p. 10.

the whole world. I believe that the idea is altogether a mistake, and has taken its rise from a mistaken nomenclature adopted by the earliest geographers in the very infancy of navigation—perhaps by Hippalus himself, who is said to have first experimentally proved the constancy of these winds in the Arabian Sea; perhaps even earlier, by the native pilots, on whose information he most probably acted. The monsoons along the coast of Arabia, or, speaking roundly, from Aden to Bombay, blow from between E.N.E. and N.E. on the one hand; from between W.S.W. and S.W. on the other; and were thus fairly entitled to be spoken of as the NORTH-EAST and SOUTH-WEST MONSOONS: the alternation being general throughout the whole basin, and our Calcutta and Madras traders in the last century, noticing that in the Sea of Bengal the direction of the wind was, on the whole, very much the same, and that the Monsoons there also were rightly described as North-East and South-West, these terms became settled; and it was, by virtue of the name, assumed that the winds throughout the whole area were north-east and south-west. On that assumption the theory of the Trade winds was brought to bear, and appeared to fit so perfectly, that no further inquiry was deemed necessary, any objection that the wind did not blow as represented being met by a ready and convenient reference to *local* influences.

But the whole problem of the monsoons is one of local influences. The application of Hadley's theory of the Trades to them, shows in what manner local influences are to be considered as acting; and the minor question arises, when are the *great* local influences which act according to Hadley's rule, to be supposed to cease, and the *small* local influences to begin? Such a distinction is impossible. Local influences, whether small or great, must act according to one constant rule; and similar causes must produce, or tend to produce, similar effects. Other and antagonistic

causes may at times prevent the effect being produced, but where such are assigned as reasons for any observed irregularity, the inquirer can at least claim to have them pointed out, and their mode of action explained.

But, in fact, the assumption that the monsoons of the North Indian Ocean blow from the north-east and south-west is erroneous. The direction of the wind varies with almost every different locality throughout the entire basin, and that in a way which sets Hadley's theory entirely at defiance. The leading principle of that theory is that wind must blow from a colder towards a hotter place: as applied to the monsoons, it is said that the continent of Asia, including the deserts of Arabia and Persia, the peninsula of Hindostan, and the vast plains of the interior, more particularly the great desert called Gobi, become intensely heated during the summer, that the superincumbent air rises, and that the denser air, from the comparatively unheated sea, presses forward to take its place. Captain Maury states this in almost so many words,* and most writers on the subject, either before or since, have expressed the same opinion. They have unaccountably overlooked the fact that the plains of Central Asia and the desert of Gobi, are separated from the Indian Ocean by a mountain-range of surpassing magnitude, which absolutely prevents any communication between the surface strata of air; that the air of the Indian Ocean, and of the desert of Gobi, can no more flow into each other, whatever may be the difference of their density, than can mercury in one basin run in amongst water in another basin standing contiguous to it; and that Humboldt, after an almost exhaustive inquiry into the physical geography of Central Asia, has left us the positive assurance that "the lofty chain of the Himalayas is a boundary to the climate of India: the monsoons, and the changes of dry

* Phys. Geog. of the Sea, § 685.

and wet seasons which depend on them, do not extend beyond it,"* an assurance confirmed by later travellers, with perhaps greater opportunities of observing.

The supposed influence of Central Asia may, therefore, be definitely set aside; that of Arabia, Persia, and Hindostan remains. Of these countries, the hottest are the arid deserts of Arabia and Persia; that bordering on the Persian Gulf, to the northward, is called by the Persians, Germisír, or hot district. "Watered by no river, and its summer heat tempered by no rain, this district well merits the appellation, being, with the exception of the opposite coast, the hottest place in the world in summer."† Is there any sign of an indraught to this "hottest place?" "The prevailing wind in the Gulf is the north-wester, called by the natives Shemál. This wind blows down the Gulf, changing its direction with the trend of the coast. In the Gulf of Oman its general direction is N.W. The Shemál blows about nine months in the year in the northern half of the Persian Gulf. It blows almost incessantly during June and part of July, seldom exceeding a moderate gale in force, and at times quite light."‡

Along the south-eastern coast of Arabia, bordering, on another side, the intense heat of the desert, there is, in the same manner, no trace of any indraught: the winds during the summer blow steadily, and even strongly, along the coast, from between S.W. and W.S.W., seldom changing the direction more than through these two points. "It is useless to attempt the direct passage from Bombay to the Gulf of Aden during the S.W. Monsoon months, or from early in June to the end of August, either for steamers or sailing vessels. There is no record of any vessel having succeeded, though some have tried it. The East India Company's steamer, 'Akbar,' attempted the direct pas-

* L'Asie Centrale, vol. iii. p. 291.

† ADMIRALTY: Persian Gulf Pilot, 1864, p. 2. ‡ *Ibid.* p. 4.

sage in June, 1846; but was obliged to bear up for Bombay, with her cutwater damaged. The East India Company's steamer, 'Feroze,' tried in July, 1849; but finding the wind and sea increase as she advanced to the westward, so as to require four men at the helm, and the decks being constantly flooded, after four days she bore up to the southward, and made the southern passage. It is usual, after the setting-in of the S. W. Monsoon, for sailing vessels bound from Bombay to Aden and the Red Sea to make what is called the Southern Passage, or to run down south of the equator into the S.E. Trade, to make their westing."*

This whole line of coast is bordered by a range of hills, which, except in isolated instances, scarcely rise to the dignity of mountains. From two to three thousand feet is, perhaps, an average height, but they are often much lower; and whatever modification in the currents of air such hills may be capable of producing, it cannot be admitted that they are sufficient to shut off the interior of Arabia from atmospheric communication with the ocean; nor has it been suggested that they do; since, on the contrary, the Arabian deserts are said to exercise such a great influence on the wind to seaward.

The Red Sea itself is, during the summer, as hot, or nearly as hot, as the Persian Gulf: even the Gulf of Aden, which has an evil reputation, is cool in comparison. In June, the change on leaving the Red Sea is surprising;† and yet, "in June, July, August, and September, the northerly winds prevail with more or less strength throughout the sea, from Suez to Bab-el-Mandeb, with little interruption."‡ All testimony on this subject is the same. In the summer months there is not a trace of indraught to what is, by universal acclamation, one of the

* ADMIRALTY: Gulf of Aden Pilot, 1863, p. 12. † *Ibid.* p. 12.

‡ Sailing Directions for the Red Sea, By Order of the E.I.C., 1841, p. 221.

hottest localities in the world. In the Red Sea and the Persian Gulf, the winds blow away from it steadily, sometimes freshly; and along the shores of the Arabian Sea they pass as easily as though, for them, Arabia had no existence. The hot plains of Hindostan, then, alone appear to produce any effect. The wind, in part of the Arabian Sea, does certainly blow towards the Punjaub; but in the Sea of Bengal it does not: it there blows away to the eastward, towards Burmah or Siam, where there is no peculiar heat; or northwards, to Sikkim and Nepaul, carrying with it that quantity of aqueous vapour which makes the rainfall there, or in Assam and Khasia, so excessive. Still, it may be said, and is said,* that throughout, the direction is from the south, and that the air, drawn in to the northward, goes away towards the east, in obedience to the law depending on the rotation of the earth. This is not the case; the one feature of the South-West Monsoon, which it everywhere preserves, is its westing; but the southing, though marked on the African or Coromandel coasts, becomes, in the middle of the sea, very faint, and frequently, on the Malabar coast, gives place to northing. "Almost all the rain squalls of the Malabar coast, and 200 miles from land, come from the northward of west; they have been experienced from N.W., at a greater distance than 100 miles west of the Konkan coast in the end of July, and off the Malabar and Travancore coasts in the beginning of that month. In August, the Monsoon does not blow so violently as in the preceding months; the squalls then veer to West and W.N.W., particularly on the southern part of the coast. N.W. and W.N.W. winds are those which prevail in this month near Anjenga and Cape Comorin;"†

* DOVE: Law of Storms, p. 65.

† ADMIRALTY: West Coast of Hindostan Pilot, 1866, p. 19. See also the Board of Trade Wind Charts, and Lieut. Fergusson's Wind and Current Charts of the Indian and China Seas. 1853-4.

and the registers in the observatories of Trevandrum, only three miles from the sea-coast, and of Dodabetta, on the highest peak of the Nilgherry Mountains, show that "at both places the wind comes from S.W., for a few days only, at the commencement of the Monsoon. It soon veers more westerly, and, by the middle of August, is fairly N.W."* Sailing from Bombay, southwards, the wind becomes more and more favourable, veering to west and W.N.W., and "on the southern part of the coast, between Cochin and Cape Comorin, W.N.W. winds prevail greatly during part of July, August, September, and part of October."† Again, near the mouth of the Hoogly, the winds in July and August range from S.W. to West, sometimes veering to W.N.W., and even N.W. In September the South-West Monsoon is on the decline; and the winds are moderate from the north-west, the rains continuing to fall in large quantities. On the eastern side of the Bay of Bengal the winds during the South-West Monsoon vary from west to north; they are indeed, at times, from south, or between S.E. and S.W., but blow generally from the north-west, in strong gusts, and with heavy rain.‡

These are not exceptional or fancy instances. They are given as the regular course of the weather, in practical directions compiled from the best authorities for the guidance of seamen; and they are such as cannot possibly be reduced to the theory already so often mentioned. There is, throughout the sea, no trace whatever of the air being drawn in to any place of greatest heat, whether on the coast of Arabia, or in the Gulf of Persia; whether near the equator, clear of the land, where the wind is strong from due west; or on the coast of Malabar where it is north-west. Nor is there any appearance of the direction being influenced by the rotation of the earth;

* W. Coast Pilot, p. 20. † *Ibid.* p. 33.

‡ FINDLAY: Directory for the Indian Ocean, 1866, pp. 54, 55.

certainly the westing in the southern parts of the sea is not due to it; for we find in latitude 4° N., or thereabouts, a strong west wind, in which the air has a relative motion towards the east of from 20 to 30 miles an hour; when the most that could possibly be given it by the rotation of the earth would be two miles an hour (900—898), supposing that the air coming from the south had, at the equator, no relative motion at all, which is not the case; and that there was no loss by friction in moving over 240 miles of stormy sea. As certainly, the rotation of the earth can have no share in the westing of the north-westerly winds on the Malabar and Burmah coasts; a westing which, nevertheless, our common sense tells us must be due to the same cause as the westing of the closely-allied south-west winds which blow more to seaward, and, in the Arabian Sea, more to the northward.

When the North-East Monsoon is examined in similar detail, we find that it presents a similar diversity of direction in the different parts of the basin, with this distinction: that whilst the prevailing and universal feature of the monsoon of summer is its westing, that of this or the winter monsoon is its northing. The two monsoons are by no means absolutely opposite to each other, as has been very generally supposed, and as their names would imply: the opposition is local, and in some parts of the basin the difference between the mean directions of the two is not more than about four points. On the south-east coast of Arabia the North-East Monsoon preserves throughout a direction from between E.N.E. and N.E., thus following very nearly the trend of the coast; but "strong land winds, called by the natives Belát, may be expected from the middle of December till the middle of March between Ras Seger and the island of Masirah; they blow from North to N.N.W., and last from one to three days, and at

times even as long as seven days."* Further to the south on the African side the direction of this monsoon still follows the coast line, and blows from between N.E. and N.N.E.; but to the eastward, towards the coast of Sindh, it prevails from between north and N.E. only during the months of December and January, and even then is not persistent. It often comes round to the west of North, and, from the beginning of February, settles permanently in that quarter.† At Bombay, the wind from February to May is frequently spoken of as the NORTH-WEST MONSOON; an exactness of name which is, however, only local, and is apt to increase the confusion which the present more usual name—also strictly local—has originated; and all down the coast, southwards to Cape Comorin, the mean direction of the wind, through the winter months, appears to be north, varying between N.W. and N.E.; occasionally, though rarely, as much as between west and east, by the north; blowing somewhat off the sea during the day, off the land during the night; but, within these limits, seldom exceeding eight points, swaying backwards and forwards with great regularity.

On the east coast, whether of the Coromandel or Orissa, there is a similar variation; the wind, during the day, blowing rather from the eastward of north, but during the night inclining often to the westward. And on the opposite side of the Bay of Bengal, the same rule holds, though not so markedly: near the northern part of the Bay, and on the coasts of Aracan and Pegu, calms and light airs are frequent; but, on the whole, the winds blow from between N.W. and W.N.W. during the day, and from the north by night, rarely veering to the eastward of north. Further south, on the coast of Martaban, the winds are stronger and the weather fine; "during all the season of the North-

* FINDLAY: Dir. of the Ind. Ocean, p. 59.
† W. Coast Pilot, p. 24.

East Monsoon, westerly breezes come on, lasting one or two days, but generally the direction is between N.N.E. and E.N.E.*

In the low-lying plains of Hindostan, the direction of the monsoon of winter is very decidedly north-west; and near the equator, to the southward of Ceylon, and between the meridians of 65° and 90° E., it is almost due north during the four months in the middle of the season, but throughout the rest of the year the wind prevails from due west.

The North-West Monsoon, south of the Line, is an extension of this westerly wind to the southward. It is commonly spoken of as a deflection of the North-East Monsoon; and, in accordance with the generally received theory, supposed to result from the air being drawn across the Line by the influence of the sun, then in extreme southern declination, and becoming a westerly wind, as it passes from the equator on to smaller circles of southern latitude. To such an opinion, observed facts give no support. It is, for the most part, a west wind, to the north of the Line as well as to the south; and, even if it were not, the difference of velocity due to the difference in length of the degrees of longitude, as a body of air moves from the equator to the parallel of 10° S. is, putting friction entirely out of the calculation, 14 miles an hour (900 – 886), and, of course, less still in lower latitudes; a difference utterly insufficient, under any circumstances, to account for the irregular force and frequent violence of the West Monsoon of the Line, near the middle of the ocean; whilst, towards the west of the basin, this westerly wind becomes northerly; blows along the coast of Africa, from about N.N.E., south of the Line as well as to the north of it; blows into the Mozambique Channel; and, to the east of Madagascar, maintains feebly, though with

* FINDLAY: *Op cit.* p. 65.

fitful violence, a general direction varying between N.W. and N.N.E., as far south as the islands of Mauritius or Réunion.

On a careful consideration of all these facts—phenomena actually observed, not described inferentially in accordance with the requirements of any theory—we find no trace whatever of such a movement of the air as has been supposed. The easting, said to be due to the earth's rotation, constantly gives place to westing, and that, in localities where such a change cannot be attributed either to an indraught towards heated plains, or to a deflection from a mountain chain. The wind on the Malabar coast turns rather towards the Western Ghauts, the mountains which border it; the westing often found on the Martaban coast, is certainly no indraught to any place of great heat; and, on the other hand, as the wind approaches the equator, and the thermal equator which lies near it, it ceases to blow towards the south; the northing which, to within two or three degrees of the equator, is the marked feature of the wind, gives place to westing; and the wind is, therefore, occasionally spoken of as the West Monsoon of the Line.

But the nature of the two winds seems to offer a very direct contradiction to the theory of Hadley. The North-East Monsoon is, it is said, the ordinary Trade wind of the northern hemisphere. The air is drawn in towards the equator by reason of the extreme heat, and appears as an easterly wind, in consequence of the continual increase of the earth's surface velocity of rotation. On the supposition that the facts are as they have been assumed for the requirements of such a theory, where, it may be asked, does the wind come from? A north-east wind, constantly blowing over an area so large as the basin of the North Indian Ocean, calls for a continual supply of air: it clearly cannot, as a surface wind, pass through the stupendous mountain chain which bounds the basin on the north-east:

it must, therefore, pass over it, and descend on the southern side. Dr. Hooker assures us that it does not; that the northerly wind does not, to all appearance, extend far into the upper strata; and that throughout the winter, as in the summer, the wind that blows over the high peaks and shoulders of Kinchin-junga is southerly.* If a northerly wind is above that, it must be intensely cold, and unbearably dry. Even at a height of 18,000 feet, the air was so dry that, at a temperature of 45° F., it did not melt but evaporate snow or ice. Its dew point was only 5° F.† Air colder and drier than that, such as we must admit existed in the higher strata, would produce the most startling effects if it was brought down to the surface. Even if, in its descent, and by compression, it acquired sufficient heat to be endurable to a native of the plains of Hindostan, the dryness of it would be, beyond measure, destructive; and, with the air at a temperature of 70° F., would be such as has rarely, if ever, been experienced in a state of nature.

The same objection of course holds, with equal strength, to the supposed supply brought to the Trade winds of all the oceanic basins, from the upper current; but it is not, at first sight, so evident as in this instance: the air that feeds the Trade wind, whether in the North or South Atlantic, in the North or South Pacific, or in the South Indian Ocean, is neither cold nor *intensely* dry: on their polar margin the Trades, are, from the very first, soft, genial, and pleasantly moist; offer a very marked contrast to the winds which, we can show by observation, have descended from above, and possess none of the properties which we can prove, by reference to tables of comparative amounts of aqueous vapour, winds so descending must have.

Since, then, the North-East Monsoon is a wind dry and

* Himalayan Journals, vol. i. p. 186; vol. ii. pp. 143, 389, 393.

† *Ibid.* vol. ii. p. 175.

pleasantly cool in the middle of winter; since, as the season advances, its coolness disappears, so that towards the latter part of it, it is extremely hot; and since the only road by which air can enter the basin, that lying to the south of the great mountain chains which stretch away past the Caspian Sea into the Caucasus, has those physical features which would cause a wind passing by it to have such properties; moderate dryness, and a temperature, pleasant in mid-winter, continually increasing as the year grows older; I see no reason to doubt that the Northerly Monsoon of the Indian Ocean is an extension of the westerly winds of the temperate zone of the Atlantic basin; winds which, in winter, descend to much lower latitudes, and blow with much greater force; which lash the Black Sea into foam, and make even the Levant dangerous; and which thus offer, on the west, a large and continuous supply of air, dense by reason of its comparative low temperature, and force it in over the south-western part of Asia—Arabia, the Euphrates Valley, Mesopotamia, Persia—with considerable pressure.

The deflections, to which currents of air so advancing over this country, are subjected, cannot be described in any detail; but our maps are, at any rate, sufficiently exact to show that, with an impenetrable mass of mountains to the north, trending away in a general direction of about E.S.E., and throwing off frequent spurs, themselves no mean mountain ranges, to the southward, the impinging wind must turn towards the south. We lose sight of the wind on the eastern shores of the Levant and Black Sea, as it enters on its course over the little-known continent of Asia. We know that the mountain chains are of such a nature as to prevent its passing to the east, or to the north. We find a wind with the characteristics which may fairly be attributed to a passage over Western Asia, emerging towards the south, beaten back towards the west

in the Arabian Sea and in the Sea of Bengal, or coming within our ken in the peninsula of Hindostan, where it glides along the southern slope of the mountains, seeking to force itself through wherever lower passes permit. The natural and only inference is, that the two are one and the same; and that the wind which we see come out from the south-western interior of the continent, into the basin of India, is the wind which we saw go in from the eastern basin of the Atlantic.

The general character of the Northerly Monsoon gives a strong support to this view of its origin. It is, says Findlay, of a much more gentle nature than the stormy South-West Monsoon. In the open sea of Arabia it blows a steady, moderate breeze from the north-eastward, with clear and pleasant weather. From November to March on the western coast of India there is splendid weather, with winds moderate and fresh from N.E. to N.W.* I have already called attention to the difference to be observed between the characters of the motions of primary and secondary streams.† This gentle equable force of the Northerly Monsoon would, of itself, suggest that the wind is a *secondary* stream, and adds greatly to the weight of the other reasons for so considering it, which I have just brought forward.

The South-West Monsoon, on the other hand, is rude, boisterous, and unsteady. In the Arabian Sea, more especially, it blows half a gale of wind through almost the whole season, so much so that it is very commonly spoken of simply as THE MONSOON. Such a wind is, in all its characteristics, entirely different from the Trade of the South Indian Ocean, from which it is said to be derived; and it would surely be a very extraordinary anomaly in physics, if the same force—that due to the expansion of the air at the place of greatest heat—were to cause, south

* Dir. of the Ind. Ocean, pp. 58, 61. † *Ante*, p. 264.

of the Line, a fine, even-tempered wind, brisk at its commencement, and with a velocity gradually diminishing, till at the equator it fell to a very gentle breeze; and north of the Line, the continuation of the same wind, boisterous, rude, and stormy. The South-West Monsoon is too different in character from the South-East Trade for us to believe that it is merely an extension of it.

And the irregular west wind which blows throughout the year on the equator, stretching out, in the southern hemisphere, well to the southward during the summer, and retreating during the winter, as the South-East Trade gathers force, and pushes itself nearer the Line; reaching far to the northward during the summer of the northern hemisphere, and, subject to the necessary deflections from the coast-line and the mountain chains, extending over the whole breadth of the basin of the North Indian Ocean, whilst in winter it gives place to a press of wind from the north, which bears it back towards the line of greatest heat and of dynamical weakness—seems to me to offer a very strong support to the hypothesis of a general motion of the atmosphere from west to east.

When to this we add the agreement between other observed phenomena, and the natural deductions from such a hypothesis; when we find that all the principal local winds can be very exactly explained as deflections of one general west wind; that other explanations which have been offered do not embrace the full detail of fact, and are frequently opposed to it; and when all observation tends to show that high overhead the air is moving continually towards the east, with the force of a westerly gale, the hypothesis which I enunciated in the beginning of this chapter ceases to be merely a hypothesis; it becomes a statement of probable fact, founded on general observation, and supported by the analysis of the principal apparent exceptions: it is as such that I repeat it here:—

The whole atmosphere, relatively to the surface of the earth, continually moves or tends to move from west to east; and the prevalent local variations from that direction are either eddies, or deflections, formed in accordance with the principles which regulate the motion of fluids.

## CHAPTER VI.

### BAROMETRIC PRESSURE.

THE particles of air, as of all other gases, exert on each other a repelling pressure which is called *elastic force.* This force, exerted by every particle in all directions, acts on every other in contact with it. It is this which causes a mass of air to strive continually to enlarge its volume, and to break down the surface which bounds it, if unsupported by a force at least equal.

Elastic force is increased by heat, and a bottle or bladder may very easily be burst by holding it before a fire, when it is full of air, and has its mouth stopped. The elastic force of the air inside becomes far greater than that of the unconfined air outside which sustains the glass or bladder; and without increasing the force inside, the same effect may be produced by removing the external air by means of an air-pump.

Similarly, preserved-meat tins are very commonly indented, as though they had been hammered or carelessly thrown about. They are hermetically sealed when the fluid inside is boiling briskly, and the steam, rushing through a small opening, has driven all the air out. When the tin becomes cold and the steam is condensed, there is a vacuum inside. The tin is not supported against the pressure of the outside air, and it is therefore crushed in.

In exactly the same way, when a mass of air is in contact with the surface of a liquid, it presses on it with the whole of its elastic force, and the liquid, if not sustained, gives

way. Thus, in the common barometer, the mercury is driven up the long tube (from which all air is carefully exhausted), and held there at such a height, that the weight of the column pressing downwards is equal to the elastic force of the air. This height is, under ordinary circumstances, about 30 inches; the weight of such a column of mercury, on a base of one square inch is nearly 15lbs., which is, therefore, said to be the weight of the atmospheric column on the same base; and the instrument has been called a *barometer*, a measure of weight, from its being considered to measure the weight of the air. The idea is a mistake, and the name has unfortunately perpetuated it. What the barometer does is to measure the elastic force of the air: with weight it has nothing whatever to do, and a barometer placed with its cistern in a close vessel, containing ordinary air, will show the same pressure whether the column resting on the surface of the mercury is half an inch high, or half a mile—whether it weighs a few grains or a few pounds to the square inch. The loose way of speaking, which has been almost universally adopted, has caused the peculiar nature of elastic force to be overlooked: it has been confused with weight and density; so that a very general opinion is that a mass of denser air will necessarily force itself into and usurp the place of lighter. This is true only in part. The elastic force of a mass of air depends on the temperature, no less than on the density. It is increased, as the temperature is increased, if the volume cannot immediately enlarge itself, that is, if the density does not immediately decrease in due proportion; and denser or not, the mass of air which has the greatest elastic force will drive back the other.

This is readily seen on opening an oven-door. The air inside has no doubt been greatly rarified by partial escape, by leakage, or by a rush out when the door was previously

opened; but notwithstanding its less density, its elastic force is greater than that of the surrounding air, and it bursts out, a gush of hot air, into the colder, denser, but less elastic air outside. This is only for a moment: the elastic force is reduced by the violence of the expansion, the elasticity of the denser air becomes the greatest, and there is a forcible entry of cold air into the oven; then it is driven out again by a second reaction, but after a few alternations, a comparative equilibrium is established, and the interchange which continues between the hot air and the cold is imperceptible. In a vessel with a narrow entrance, as a flask, or—an extreme instance—a thermometer tube, the air may be very considerably rarified, but if the temperature be so adjusted that its elastic force is kept equal to that of the air outside, the two will remain in sensible equilibrium, though in contact, and of very different densities.

It must, therefore, be carefully borne in mind that the elastic force of air is not its weight, and is connected with it only so far as it is increased by the pressure caused by the weight. The elastic force of a mass of air is increased as its volume is diminished by compression, and the weight of the atmospheric column, bearing on the air of successive strata, does compress it. The compression stops at that point at which the elastic force is equal to the pressure; and thus, in general terms, the weight of the superincumbent column may be considered as the cause of the amount of the elastic force of the air, at any height; and the elastic force may, on the other hand, be considered as the measure of the weight of the atmospheric column above. It is not so, however, with any exactness. The disturbing influences continually operating near the surface of the earth, the variations in temperature and humidity, each variation effecting a variation in the elastic force of the lower air, whilst the upper air remains un-

changed, are but remotely connected with the weight of the column; and whilst the upper air pursues its uniform course from west to east, volumes of the lower air may, and frequently do, press one into the other, consequent on a difference of elastic force, giving rise to winds of an irregular but often continuous nature.

Of these, the Scirocco, already spoken of, is one. When the air over the desert, which, in winter, is comparatively cold and dense, is warmed by the sun in his progress northward, its elastic force is suddenly increased, the equilibrium is violently destroyed, and a rush or a series of rushes of hot air outwards takes place, which, in Egypt, is said to continue for fifty days, and is, therefore, known as Khamsin, or Fifty. After the south-easterly Scirocco comes a north-westerly breeze.* It is, as in the case of the oven, the reaction following the violence of the expansion: the colder, denser air pressing in on the space of the warm, which has expended a great portion of its elasticity. The same thing takes place in South-Eastern Australia and the adjoining seas; after a Hot Wind from the north-west comes a cold gale from the south-east.†

Of a similar nature to the Scirocco, and the Hot Wind of Australia, is the north-easterly wind, which frequently in spring blows over our own country. The cold air of the Russian Steppes, air whose temperature in Siberia sinks as low as — 40° F.,‡ has its elasticity enormously

* SMYTH: Mediterranean, p. 251.

† *Ante*, p. 61.—KING: Survey, etc. vol. ii. p. 248.

‡ Very much lower temperatures have been occasionally noted. Admiral Von Wrangell speaks of — 65° F. as common in January in the district of the lower Kolyma [*op. cit.* p. 49]; — 72° F. is said to have been observed in the neighbourhood of Iakutsk, a degree of cold beyond any reported from other localities, though Dr. Rae experienced — 70° F. at Fort Confidence on the shores of Bear Lake [W. H. HOOPER: Tents of the Tuski, p. 384]. Dr. Kane is, however, of opinion that such observations are not to be depended on, thermometers being exceedingly capricious in their indications at temperatures below — 40°. He mentions

increased by the approaching summer. Towards the end of April, that portion of it which has pressed outwards to the west, blows over England, a wind still exceedingly cold; and causes that week or ten days of bitter weather which, falling commonly about the time the blackthorn is in flower, is spoken of familiarly as "The Blackthorn Winter."

The force which produces these winds is, however, short-lived: the act of once driving the air out, the mechanical expansion of the volume, exhausts it. The air which remains over the heated area is then less dense than the air outside; and, if other forces do not prevent, a continuous but insensible interchange between the two goes on. These winds, therefore, can in no way be considered as occasioned by an absolutely or even relatively high temperature. The influence on atmospheric movement of a temperature uniformly high, or uniformly low, is extremely small; but on the other hand, fluctuations in temperature, changes from high to low, or from low to high, giving rise to local differences of elastic force, disturb the conditions of equilibrium, and produce important and well-marked effects.

Effects still more marked, still more important, are produced by the varying conditions of atmospheric humidity; that is to say, by changes in the quantity of aqueous vapour in the air of different localities. The elastic force of the air as, in a state of nature, it lies over the earth and sea, is the sum of two different forces; that of the pure air, and that of the aqueous vapour which is everywhere intimately mixed with it. It is as a whole only that it is measured, and that it acts in maintaining or disturbing

one instance in which *eleven* thermometers, all good, varied between — 56° and — 80°, the mean being — 68°; and another in which six thermometers ranged from —50° to —71°. [Met. Obs. in the Arctic Seas, p. 50, in Smithsonian Cont. to Knowledge, vol. xi.]

equilibrium: volumes of air, the elasticities of which are each equivalent to 30 inches of mercury, will sensibly balance each other, whatever may be the different proportions in which vapour enters into their composition, and whatever may be the elastic force respectively due to the vapour. But if from one of these volumes the aqueous vapour be suddenly withdrawn, its elastic force is lessened by the amount of the elastic force of the vapour: if the vapour has a tension equivalent to one inch, the tension of the volume is reduced to 29 inches; and between it and the adjoining volume, whose tension remains at 30 inches, there is an immediate disturbance of equilibrium, a disturbance violent in direct proportion to the suddenness of its cause.

The elastic force of the aqueous vapour which air contains is that due to the temperature of the Dew Point; this, at sea, in the neighbourhood of the equator, may be estimated as about 80° F., at which the tension of the vapour is, in round numbers, equivalent to one inch of mercury. This aqueous vapour is not raised exclusively, or even principally, from the equatorial part of the ocean; the Trade winds, during their whole passage, are taking it up freely, and carrying it, together with the air, towards the line of greatest heat. There, as the wind ceases, it is precipitated. Of the enormous quantity of rain which falls in the region of equatorial calms and light winds, I have already spoken. I again allude to it, to call attention to the effect necessarily produced by the *sudden* abstraction from the air of a very large proportion of its elastic force. In such localities as that to which our old navigators gave the simple name of THE RAINS; where, as modern observers tell, the fresh water lies in pools on the top of the salt; where the boomboats of a line-of-battle ship are half filled with water in a few minutes,—it needs no hygrometric or barometric measurements to convince us

that a tropical shower, still more a long-continued downpour, removes from the air a great quantity of its moisture and of its elastic force.

The elasticity of air, and that at a high temperature, causes the vacuum thus locally formed to be immediately filled up; but the general atmospheric pressure of the whole district is sensibly lowered by the copiousness of the rain, and is kept low by the continuous nature of it. The average height of the barometer in the neighbourhood or THE RAINS is 2-10ths of an inch less than it is a few degrees either to the north or south, and the necessary consequence of this, of the prevailing low pressure near the equator, and of the comparatively high pressure further away, is an influx of air which, gathering moisture as it advances and discharging it as it arrives, gives a new strength to the Trade winds, and causes them occasionally, in low latitudes, to assume somewhat of a boisterous and primary character.

I bring forward in this manner the equatorial rains, and the Trade winds, as typical instances of the action of this force derived from the condensation of aqueous vapour, not only because they are instances in which these forces act on the largest scale, and in the most continuous manner; but also, and principally, because they are the instances that will come most home to the mind of the seaman, or of any one who has met Father Neptune on the Line: but the same sequence is to be observed in all parts of the globe; a moist wind, causing heavy rain; and heavy rain, causing a moist wind, mutually react on each other, in localities as various as their climates.

It is thus to the almost unceasing rains near the eastern foot of the Andes, that we must attribute the peculiar strength of the wind which, in the dry season, blows up the valley of the Amazon. This wind, a pleasant breeze at sea, is, on shore, 500 miles inland, a gale so

violent that a man can scarcely walk against it; whilst, during the wet season, it dies away even to the coast line, and is succeeded by fitful westerly squalls.

Similarly, near Sierra Leone, a place which, on account of the poisonous malaria engendered by excessive humidity, has been aptly called "The White Man's Grave," the west wind, during the whole of the wet season, blows home to the coast, and passes far into the interior. There can be no doubt that the rains which fall heavily in Bornu, flooding the country and swelling Lake Tsad, in the months of July and August, are brought in from the Atlantic by the westerly winds which then prevail, and which, so far as our information goes, extend from the seaboard of the Atlantic, on the west, to the highlands of Abyssinia, on the extreme east.*

The heavy rains on the Western Ghauts, too, seem to give increased force to the Westerly Monsoon, a wind which, on the east, or Coromandel Coast, where but little rain falls at that season, is comparatively gentle; whilst the Northerly Monsoon, bringing to the Eastern Ghauts the moisture of the Sunderbunds and the Bay of Bengal, causes a rainy season in November and December, and blows with a violence which it has in no other part of the Indian Basin.

It is again to a similar agency that we must refer the irregular and furious gales which are so frequent in all those districts of the Ocean, where hot and cold currents meet together. Air, which has rested for any time on the surface of a hot current has not only a high temperature, but at that high temperature is almost saturated with vapour. When it clashes with the colder air, or is driven over the colder water, this vapour is freely condensed into rain or fog. It is this sudden condensation, whether

* DENHAM, CLAPPERTON, and OUDNEY: Northern and Central Africa, vol. i. p. 437.—MARKHAM: Abyssinia, pp. 411, 417.

partial or entire, this sudden loss of elastic force which, in a great measure, gives rise to violent and apparently capricious storms off the Banks of Newfoundland, and in the North Atlantic, where the Gulf Stream and Arctic Current run into each other; off the mouth of the La Plata, and the east coast of Patagonia, near the meeting of the Brazil Current with that from Cape Horn and the Falkland Islands; off the Cape of Good Hope, where the hot waters of the Natal Current force themselves to the southward, into the cold masses of the Great Easterly Drift; and in other less notable places, wherever currents of widely different temperatures are driven against and into each other. The storms of the Atlantic coast of North America, which have conferred on the Gulf Stream the title of "the Weather-breeder," belong distinctly to this class. The Gulf Stream, as has been said, is an enormous body of warm water passing between banks of cold. The two waters do not mingle, neither does the air over them; but between the two there is a frequent interchange, and, as it were, an interlacing, quite sufficient to account for the gales which, in frequency and fury, equal, if they do not out-top, those of Cape Horn or the Cape of Good Hope, and render it, as a rule, unadvisable for homeward-bound ships from the West Indies or the coast of America to take advantage of the help a favourable current of from two to four miles an hour would seem to offer.*

That storms thus due to the meeting of hot and cold currents, and of masses of air at very different temperatures, containing very different quantities of vapour, are frequently of the nature of whirlwinds, seems satisfactorily established by the testimony of hundreds of observers; and though many have questioned this—though there is, therefore, reason to believe that they are not so always,

* MAURY: Phys. Geog. of the Sea, § 168.—ADMIRALTY: Current Chart of the Atlantic, 1868.

the known habitude of fluids to assume a rotating motion when rushing through a small opening, the easily seen fact that water running out through the plug-hole at the bottom of a bath does circle round and round it, is sufficient to convince us that air rushing into a comparatively small vacuum, suddenly formed, may very often do so in a whirling and gyratory manner, which manifests itself to the observer by continual and continuous changes in the direction of the wind.

The Tornados of the west coast of Africa are described as frequently having this circular motion; but it has been most commonly noticed in the storms off the mouth of the La Plata, where the custom of English sailors has given the name Pampero to every gale that blows. It seems highly probable that the true Pampero, a wind off the Pampas, and therefore a volume of dry air, may, on striking against the mass of moist air to seaward, turn back on itself, and assume to some extent a rotatory motion. There is, from evidence, strong reason to believe that a Pampero very often does rotate in this manner near the sea coast, both over the land and over the water; but, so far as I am aware, no observations of any value have been made with a view of distinguishing between the Pampero, which really comes off the Pampas, and the more local storm which is merely the rush of air into the vacuum caused by the sudden condensation of aqueous vapour.

The alternating winds known as land and sea breezes would seem to be, to a great extent, caused in a somewhat similar manner, by the changes in the elastic force of the air due to considerable fluctuations in the quantity of aqueous vapour it contains. Land and sea breezes are winds which are experienced on most intertropical and on some temperate shores, blowing from the land during the night, and from the sea during the day. Within the

tropics, the alternations on a coast line where there are no strong prevailing winds are very marked. About 10 or 11 o'clock at night the wind begins to blow off the land, increases gradually in strength to a fresh breeze, and as gradually dies away again, being succeeded about sunrise by a dead calm. Towards noon the sea breeze springs up, blowing in the exactly opposite direction; like the other, it gradually freshens and declines, and dies away about sunset. But this regular alternation and exact opposition is, comparatively speaking, rare; it is, indeed, seldom found, except on the shores of islands on or very near the equator, where it is not broken in on by other stronger and more lasting winds. Some of the islands of the Eastern Archipelago afford very perfect examples of it: the land breeze off the coasts of Java and Sumatra, laden with the sweet smell of various aromatic shrubs, imparts a sensuous pleasure, the charm of which almost equals the enthusiastic descriptions of writers of poetry or romance: round the islands of the South Pacific, too, during the summer months, the direction of the wind almost at right angles to the coast is strongly marked.* In the Gulf of Guinea the alternation is also very decided; the land wind being often most deadly to the crews of ships near the coast, in consequence of the poisonous miasma which it brings off from the adjoining swamps; and, beyond the tropics, at Beyrout, the land breeze, during the summer, brings off the sickening stench of the silk stores at about half-past ten every evening, with unfailing regularity.

More commonly, however, a prevailing wind, whether Trade or Monsoon, considerably modifies the direction or even the alternation of these breezes. When such a wind blows strongly on to a coast line, it is a permanent sea breeze, and blows by night as well as by day, though,

* FITZROY: Voyage of the "Beagle," vol. ii. p. 557.

perhaps, occasionally with rather less strength. Such a wind is the Trade which blows home to the coast of Brazil from due east; or the Westerly Monsoon which, during its season, blows very fixedly from seaward against the west coast of Hindostan; but when the prevailing wind blows along the line of coast, it does frequently vary its direction according to the time of day, and without becoming strictly a land or sea breeze, inclines now towards the one, now towards the other. This is seen on the coasts of Hindostan during the prevalence of the Northerly Monsoon; on the western side of the peninsula it frequently blows rather from the east of north by night, veering towards the west during the day; and conversely on the eastern side, its direction which, during the night, is nearly due north, inclines during the day very decidedly towards the north-east. It is the same on the west coast of Mexico, where the difference between the directions of the land and sea breezes is seldom more than four points.*

It has been suggested, and very generally admitted, that the cause of these winds is a great difference existing between the temperature of the land and of the sea. It is said, that during the day the land becomes much the hotter, and that the colder, denser air from seaward presses in on it, and drives it up; but that during the night, the land, radiating much more freely than the sea, becomes far colder, and its air consequently denser; this presses outwards, forcing itself under the lighter air of the sea. It is said that exact illustrations of this, on a small scale, are afforded by the indraught of air to a large fire kindled in a field, and by the cold air which seems to flow out on all sides from a large piece of ice in the middle of a room.

Such an explanation is not, however, entirely satisfactory. There may occasionally be a certain change in the

* BASIL HALL: Journal on the Coasts of Chili, Peru, and Mexico, App. i.

relative temperatures of the land and the sea, though never to anything like the extent which the illustration of fire and ice would imply: and yet, even with those excessive differences, the currents of air are, as currents, absolutely imperceptible; and become perceptible only when, by confinement, their velocity is increased. But the shores where land and sea breezes are most strongly marked are shores where the adjoining land is of such a nature that it does not undergo any undue heating by day, or chilling by night. Almost without exception, the land, off which the land breeze blows strongly, is thickly wooded, or covered with some sort of verdure which effectually prevents any excessive radiation. Java or Sumatra, the Guinea Coast, or the Coast of Central America are notorious for the dense tropical vegetation which covers the soil; and even round Beyrout the country is deliciously green with mulberry plantations. It is not over such land that air experiences great changes. The forest growth is equally a safeguard against extreme heat at noonday, or extreme cold at midnight; and there is no solid reason to suppose that there is, in such localities, any difference worth mentioning in the relative temperatures on shore and on the sea. On the other hand, where the soil is not so protected, where the alternations of heat and cold are, or may be supposed to be, much more marked, the land and sea breezes are very faint, or are absolutely unknown. Along the south coast of Arabia they do not blow; in the Red Sea, or in the Persian Gulf, they are unheard of;—places where certainly the extreme solar heat is attained, and where, from the nature of the soil, the nocturnal radiation must be very great. The Red Sea and the Persian Gulf are, it is true, comparatively small sheets of water; but they are larger than Lake Tanganyika, or the River Tapajos, where Captain Burton and Mr. Bates, respectively, found

the alternation of land and sea breezes going on night and day with great regularity.*

It seems therefore probable that these winds are due, not so much to any relative difference of temperature, as to a considerable difference in the relative force of the aqueous vapour contained in the sea and land air. In warm climates, the air over the low land near the coast undoubtedly contains a great quantity of vapour; but it does not contain so much as air, at the same temperature, over the sea; its dew point is therefore lower; and the elastic force of its vapour is less. Thus, then, when two contiguous masses of air, one over the land, the other over the sea, have established themselves in a state of equilibrium, if the whole of the aqueous vapour be withdrawn from each, more elastic force is taken away from the sea air than from the land: the land air remains possessed of greater force, and thrusts itself out to seaward. On the other hand, if equilibrium be established between two masses of dry air, so situated; as the sea air becomes charged with aqueous vapour, its elastic force increases, that of the land air remaining unaltered, and the air from the sea presses inwards to the land.

Such an extreme case neither does nor can occur anywhere in nature; but, though in an exaggerated manner, it represents what does actually take place wherever land and sea breezes blow. When night closes in, the air of the sea and land are in relative equilibrium along the coast line, but the dew point of the sea air is higher than that of the land, and the elastic force of its vapour is consequently greater. During the night, whilst the dispersive power of this vapour is causing it to diffuse itself into the upper regions of the atmosphere, the lower temperature

* BURTON: Lake Regions of Central Africa, vol. ii. p. 143.—BATES Nat. on the Amazons, vol. ii. p. 149.

causes evaporation from the surface of the sea to go on more slowly. Elastic force is thus continually lost by the diffusion; and is not, as during the day, replaced by evaporation. Over the land, the vapour is, in the same manner, diffusing itself; spreading into the dry air above, or further inland; but its elasticity, and its dispersive power which varies with its elasticity, is less than that of the vapour over the sea; and it does not diffuse itself with the same rapidity. The aggregate elastic force of the land air thus, after a few hours, remains greater than that of the sea air, and a land breeze begins to blow. Through the day, the process is almost entirely reversed. The equilibrium established by sunrise is disturbed by the increased evaporation from the sea, and the augmented elastic force of the sea air; so that as the sun gains strength, the sea breeze gradually comes on.

The system of means, which has been very generally adopted in Meteorological returns, does not permit us to examine, with any accuracy, the hourly barometric pressure, as compared with the component pressures of the dry air and the aqueous vapour; neither have we any series of observations that establish the continually changing condition of the air over the sea. General Sabine has shown that, at Bombay, in the winter months, when land and sea breezes are felt, the mean pressure of dry air at 10h. a.m., is 29·391 in.; and at 4h. p.m., is 29·195 in.; the difference between the two being nearly 2-10ths of an inch; whereas, in the summer months, the difference at the same hours is not more than 8-100ths of an inch.* This difference of 2-10ths of an inch would seem to imply a corresponding but opposite change in the force of the aqueous vapour; an inference fully borne out by the hygrometric observations made by Colonel Sykes, in March, 1828, which gave the

* Rep. of Brit. Ass. for 1845, p. 73, etc.

mean elastic force of the vapour at sunrise, between 9h. and 10h. a.m., and between 4h. and 5h. p.m., as, respectively, ·514, ·715, and ·860 inches.*

In addition to these observations, which are, of themselves, almost sufficient to establish the view of land and sea breezes which I have here taken, is the fact, already mentioned, that the land breeze is nowhere found in any strength except off a well-wooded coast. The trees put a decided check on the dispersion of the vapour, which remains, therefore, in the air, so that the elasticity is comparatively little changed. Banks of fog over the land occasionally act in the same manner. According to Dampier: "The seamen that sail in sloops, or other small vessels, in the West Indies, do know very well when they shall meet with a brisk land wind, by the fogs that hang over the land before night; for it is a certain sign of a good land wind, to see a thick fog lie still and quiet, like smoke, over the land, not stirring any way; and we look out for such signs when we are plying to windward; for if we see no fog over the land, the land wind will be but faint and short that night."† Through such fog the vapour cannot diffuse itself; but when the sky is clear, and the soil dry, radiation and dispersion keep pace with each other.

A range of mountains inland is also frequently found to strengthen the land breeze: it prevents all horizontal dispersion of vapour into drier air in the interior of the country. This may be especially noticed along the coast of Syria, where the Lebanon range forms a barrier only a few miles distant, and where the land breeze blows with a freshness very unusual out of the tropics.

The difference of elastic force thus occasioned whether by

* Phil. Trans., 1835, p. 210. † Voyages, etc., vol. ii. part iii. p. 40.

changes of temperature, or by changes in the quantity of aqueous vapour contained in the air, may, and very frequently does, cause a sensible wind, blowing towards the place of least pressure; but it is far from correct to say, as is commonly said, that wind always blows towards the place of least pressure. This is the assumption which many very distinguished writers on Meteorology have taken as their basis; it is an assumption that would seem to be thoroughly warranted by hydrostatic experiments, and by theoretical considerations; but it is not borne out by the evidence of fact.

The discrepancy arises from this: that the problems which the motion of air continually presents to us have been treated as pertaining to Hydrostatics, and admitting of a mathematical solution, rather than as forming a peculiarly perplexed branch of Hydrodynamics, a science which, at present, is entirely experimental. The error in this particular case is equivalent to saying that, because water cannot, of itself, underrun mercury, therefore natural air cannot be forced into a volume of compressed air: it is equivalent to ignoring the possibility of causing a blast by a pair of bellows, as well as by holding a newspaper before the fire. But a draught can be made by means of a pair of bellows; compression can be produced by a force-pump: and a wind, which, blowing steadily, meets with a check, forces itself against the obstacle, so as to raise the atmospheric pressure, and to keep it raised; it causes the high pressure, is not caused by it; it blows towards the high pressure, not from it.

It is thus that the barometer stands high in those parts of the Ocean, Atlantic or Pacific, where the westerly winds force themselves against the coast line; where they are divided, and turn towards the equator as the Trade winds, or incline towards the poles of their respective hemispheres. An exactly similar effect may be produced by blowing with

a pair of bellows against a wall. The current of air will spread itself out, and be felt at some distance along the wall, blowing at right angles to its primary direction, or even altogether reversed; but on that part where it first strikes, the pressure will be very great; a fact not easily proved by a barometric measurement, but which may be shown very clearly by the way in which it can hold up a piece of paper, or can paralyze a fly in the middle of its endeavours to escape. A sharp puff of wind will often hold even a strong man thus jammed against a wall; there can be no doubt that a barometer observed in such a locality, under such circumstances, would show an exceptionally high reading;* and it is in exactly the same way that the barometer stands permanently high in those places where the great westerly winds divide against the continental barrier—that is to say, towards the eastern shores of each oceanic basin, and, for the most part, between the thirtieth and fortieth parallels of latitude.

From a similar cause, the barometer in Siberia has, during the winter, a mean height greater than any other locality in the world. The westerly winds, which at that season blow strongly over all the western part of the continent, carry the air on to the steppes of Northern Asia, where it is pent in by the mountainous country which extends from Thibet to the Polar Sea, and from the meridian of 80° E. to the shores of the Pacific. The mountain ranges which traverse this wide area, the Altai, the Yablonoi, and others—with whose peculiarly wild scenery the sketches of the late Mr. Atkinson† have made us familiar—run for the most part in a direction of from W.S.W. to E.N.E. A great quantity of the air pressed against them from the west is thus able to force its way through, and appears to be finally deflected southwards by

* See *post*, p. 332.

† Oriental and Western Siberia.—The Upper and Lower Amoor.

the mountain range of the Corea, of which little is known, except that it runs nearly due north and south, and maintains an elevation of from five to ten thousand feet, through ten degrees of latitude. Thrust against this, and turned violently southward, as the Northerly Monsoon of the China Seas, the air in the Gulf of Pecheli and in the Yellow Sea, is kept at a high pressure throughout the winter, when the mean, as shown by the barometer, is equivalent to 30·2 inches of mercury. Great as this is, it is, however, surpassed in the low country west of the mountain district, where the barometric mean for January is, when reduced to the level of the sea, 30·4 inches.* It is the warming up of this mass of air, condensed at a very low temperature to this extreme pressure, which causes it to burst violently out over Western Europe in the stormy and long-continued easterly winds of spring. By them the pressure is relieved, and the gentle breezes of summer do not again accumulate it.

A correspondence of geographical position, in a bight enclosed by high mountains, and open to an almost perpetual westerly wind, might lead us to expect a similar high pressure along the north-west coast of North America, more particularly in the neighbourhood of Prince William's Sound. But this bay—backed though it is by stupendous mountains, several of which tower to a height of 13, 14, or even 15,000 feet above the sea—is open to the south and south-east, as well as to the south-west; much of the air pressed in can thus readily force its way out again, and does do so in northerly gales down the coast. The air too which blows in from lower latitudes of the Pacific, is warm and moist almost to saturation; and the heavy rains which deluge the adjoining country throughout the whole year, and more especially in winter, tell their own tale of the

* ALEXANDER BUCHAN: Handy Book of Meteorology, 2nd Edit. Plate II.

large amount of elastic force which they take away. Even with these reductions the pressure is still high, ranging from a mean of 29·9 inches in summer, to 29·7 in winter.*

A series of experiments made by Sir Henry James in the neighbourhood of Edinburgh, establishes the fact that when there is a strong breeze, the barometer stands higher on the weather side of a wall, and lower on the lee side, than it does on perfectly open ground; and that when a barometer is thus by its position exposed to the pressure of condensed or rarefied air, it is subject during heavy puffs of wind to remarkable fluctuations, and to those sudden risings or fallings commonly spoken of as *pumping*, which are not shown by a barometer placed, for instance, in the middle of a field.† I have already considered the causes of this condensation on the weather side of a wall: the rarefaction on the lee side, or in a sheltered room is, in its nature, exactly the same as that which causes the action of the Odorator; and we are forced to believe that as we find a high pressure on the weather side of the principal geographical barriers, the coast lines, and mountain chains, so also on the lee side, careful observation will prove that the pressure is exceptionally low. Admiral Fitzroy says that in Eastern Patagonia this low pressure is clearly marked, accompanying a cold, dry westerly wind, when a warm, moist westerly wind is blowing strong, with a high barometer, on the western side of the Andes.‡

In a former chapter I have explained how a wind blowing away from a range of mountains or a coast line, necessarily causes a tendency to a vacuum, a tendency which is much increased when a continuous upper current blows strongly in the same direction. The theoretical certainty that

* BUCHAN: *Op. cit.* Plates I. and II.

† Trans. of the Roy. Soc. of Edin. vol. xx. p. 377, etc.

‡ Weather Book, p. 124.

such a tendency exists, strengthened by the knowledge that it has been observed by barometer both in Patagonia to leeward of a mountain, and in Edinburgh under the lee of a house, leaves little doubt that when accurate observations are made in other situations where the barriers to atmospheric currents are greater, the difference will be found even more marked. And it may be worthy of notice that in the "Far West" of the United States, east of the Rocky Mountains, the heights determined by a barometer, thus placed in an exceptionally rarefied atmosphere, will probably, when a series of levels is carried from the Atlantic, be found to err in excess. This may possibly have been discovered during the progress of the Great Pacific Railway; but in the hurried way in which the work is said to have been conducted, a mistake of a hundred feet, one way or the other, would be a mere trifle.

The effect which absolutely impassable barriers, such as mountain ranges, produce on atmospheric pressure, and the influence which, in a smaller degree, coast lines and the different velocities of land and sea air exercise, by constantly operating in the same localities, enable us in some measure to trace out the causes of certain irregular fluctuations of the barometer. If two currents of air, streaming in opposite directions, clash, there must be, to a greater or less extent, compression, and an increase of elastic force; and since, as has been shown, the atmosphere has a continuous motion from the west, it follows that at those places where—whether from local peculiarities, geographical configuration, variation of temperature or humidity, or from any other cause, the motion of a considerable body of air is reversed, so as to form a wind from the east, the elastic force must, for the time being, be greater than when the wind blows in its normal direction. This is equivalent to saying that the barometer is high with easterly winds,

low with westerly; a rule, which though not without exceptions, is so nearly so that it may very safely be adopted in the temperate zones.

Within the tropics the Trade winds are so regular, and the barometer so steady, that no such law of change can be laid down. It can only be said that in those localities near the Line, where the easterly winds do not blow, and where westerly winds very often do, the barometer is uniformly low; but this, as I have shown before, is due rather to the excessive and almost continuous condensation of aqueous vapour; and the only marked instances of barometric fluctuations are invariably associated with storms, to which the terrific fury of the wind, and the peculiar physical characteristics have given an extraordinary interest, which entitles them to distinct consideration.

## CHAPTER VII.

### HURRICANES OR CYCLONES: REVOLVING WINDS AND STORMS.

THE localities in which HURRICANES, under different names, occur, have been already mentioned. They are the West Indies, the South Indian Ocean, the Bay of Bengal, and the China Sea.* In other places, storms, of a nature somewhat similar, have indeed been met with; but they seem to be, for the most part, neither so violent nor of such long duration as in those I have just named,—in all of which the characteristics that distinguish storms of this class are most noticeable.

Of these characteristics, the chief is the continual shifting of the wind. The change of direction is commonly gradual, and in one place does not extend to more than a few points; but at other times the wind flies right round the compass, and in a sudden shift, or after a short interval of dead calm, blows from the very opposite quarter with greater violence than ever. In the West India Islands, where these storms have been longer known and more carefully studied than anywhere else, it is observed that when there is this sudden change through sixteen points, whether with or without an intervening calm, the shift is invariably from north-east to south-west. It is observed also that the storm invariably travels towards the west at the rate of about ten miles an hour: that is to say, that it begins

* *Ante.* pp. 28, 83, 72, 51.

sooner in one island than in another to the west of it. A storm which began at Barbadoes a little before midnight on the 10th August, 1831, did not reach St. Vincent, 80 miles to the west, till seven o'clock the next morning.* In the South Indian Ocean, the sudden change through sixteen points is always from south-east to north-west, but the body of the storm moves to the westward, at about the same moderate rate of 10 miles an hour. It is, therefore, in both cases, quite certain that the furious wind which, at any particular point, is blowing at the rate of 100 miles an hour or more, in constantly changing directions, does not blow onwards in a straight line. Under these circumstances, and knowing that fluids in motion, when interrupted, have always a tendency to circle round and to form a whirl, it scarcely needs further proof that these storms are whirlwinds, and, so far, similar to the little whirls which, visible by the dust they carry, we can see dancing at any street corner on a windy day, although they are both more violent and many thousands of times larger.

It is from this rotating in a spiral or circle, the chief and distinguishing characteristic of storms of this class, that they have been called CYCLONES,† a name which, it must be pointed out, refers merely to this circling motion, and in no way to the extreme force of the wind; so that the practice which has of late years gained ground amongst newspaper writers of calling any violent gale a Cyclone, is both incorrect and unmeaning.

Repeated observation has further shown that Cyclones always turn the same way at the same place. In the West Indies, the rotation of the storm is N.W.S.E., or *contrary* to the movement of the hands of a watch. In the South

* Sir WILLIAM REID: An Attempt to Develop the Law of Storms, 1846, p. 27.

† κύκλος, a circle. The same word appears in the very modern *bicycle*.

Indian Ocean, it is N.E.S.W., or *in the same direction as* the hands of a watch; and to this law no exception has been observed. In the Bay of Bengal and in the China Sea, a similar rule holds; and it may be laid down, as established by an enormous amount of evidence, that, in all north latitudes, Cyclones revolve from right to left, and in all south latitudes they revolve from left to right. This LAW OF ROTATION—for the proof of which we are indebted to the laborious investigations of Sir William Reid in the West Indies, Mr. Piddington at Calcutta, and Mr. Thom at Mauritius—refers, however, in the first instance, only to this particular class of storms; and though, in some certain cases, applicable also to storms in other parts of the world, it is incorrect to apply it to them indiscriminately, and often without proof that they revolve at all. Sir William Reid himself has committed this mistake; but his long-continued study of Cyclones in the West Indies, seems to have led him to believe that every storm, in every part of the world, was of the same nature; a conclusion which is by no means in accordance with a general and unbiassed view of even those special instances which he has brought forward. To this branch of the subject I shall have occasion to revert. For the present I confine myself to the consideration of the rotating storms in the localities already named.

The size of these storms—that is, the area over which the violence of the wind is felt at the same time—is very variable. They are occasionally not more than 50 miles in diameter, but more commonly are much larger. In February, 1845, the merchant brig, "Charles Heddle," on meeting with a Cyclone in the South Indian Ocean, put herself before the wind, and continued to scud right before it for four successive days and nights, in which period she sailed round the storm *five* times, and ran upwards of 1,300 miles through the water, though her actual change

of place did not much exceed 300 miles. . During this run she seems to have kept at a nearly uniform distance of about 40 miles from the centre, so that this storm was certainly more than 100 miles in diameter.* Mr. Piddington thinks that they may be of any size between 50 and 500 miles in diameter; whilst some other writers assign them far greater possible dimensions, and believe that they have traced Cyclones of 1,500 miles in diameter.† Cyclones of such an enormous size seem to me in the highest degree doubtful. Those mentioned are for the months of November and December, when, practically speaking, Hurricanes are never met with in the West Indies;‡ and they are described as having occurred very far to the northward and eastward, in the Atlantic, far beyond the ordinary limits. Whilst, therefore, admitting that violent gales were experienced at these times, in these places, it requires very positive evidence indeed to convince us that Cyclones of this extraordinary size really occurred at an unusual season of the year, and in a locality where they are almost unknown. Neither am I quite prepared to admit that, even under less exceptional circumstances, Cyclones attain the enormous magnitudes which have been assigned them; believing it to be much more probable that several such storms, distinct from each other, and of very large but still moderate dimensions, frequently co-exist in a comparatively small area, as Mr. Piddington has shown they certainly sometimes do,§ and as we know that the dust whirlwinds do in the neighbourhood of Lahore or Tien-tsin.

The wind in a Cyclone blows, as has been said, with the

* Naut. Mag. 1846, pp. 427, 459.

† HENRY PIDDINGTON: The Sailor's Horn-Book for the Law of Storms, 4th Edit. p. 94.

‡ *Ante*, p. 28.

§ *Op. cit.* p. 96.

greatest known violence. The extreme danger to life and property, not only at sea but even on land, renders it impossible to carry on delicate observations with much accuracy,* and the descriptions of Hurricanes, written from memory by men who have just escaped from destruction, and whose nerves are unstrung, are frequently sensational rather than exact. The velocity of the wind has thus never been correctly measured; and though it is commonly said to be about 120 miles an hour, Mr. Thom, taking into account "the details of damage done to solid buildings—enormous bodies raised in the air, trees torn from the earth, and the masts of vessels, secured by powerful stays, snapt like fragile reeds"—considers this estimate to be far too low.†

But whatever the strength of the wind may be, it is quite certain that it increases from the outer boundary of the circle towards the centre, near which it suddenly ceases; there, as a rule, there is a dead calm. The most violent gale conceivable, at its height, dies away in a few minutes. On shore, the sky clears, and the sun or stars, till then obscured by deep, purplish-coloured clouds, shine out.‡ Afloat, the surface of the water remains indeed disturbed; there is an ugly cross-sea, but, to the inexperienced navigator, there is all the appearance that the storm has past. As suddenly as it died away, it breaks out again from nearly the opposite quarter. It is in the suddenness of this outburst, more than in its violence, that the especial danger of the centre of a Cyclone consists: if it finds a ship at all unprepared, if it takes her aback, and against such a sea forces her into sternway, the chances are that she is not heard of again.

It is, therefore, a point of the most vital importance to

* Besides, any anemometer would probably be blown away.

† ALEXANDER THOM: The Nature and Course of Storms, 1845, p. 170.

‡ M'LEOD: Travels in Eastern Africa, vol. ii. p. 110, *et seq.*

keep a ship, if possible, out of the centre, the bearing of which is determined by the simple rule:—"Look to the wind's eye; set its bearing by the compass; take the 8th point to the *right* thereof, and that will be the bearing of the centre of the storm, if in north latitude; or, if in south latitude, the 8th point to the *left* of the direction of the wind." *

But, having so determined the bearing of the centre, it is necessary for the navigator, in judging of the best way in which, under all the special circumstances of his case, he can avoid it, to take also into consideration the direction in which the storm is travelling. The whole body of the storm, as I have already said, whilst rotating with excessive velocity, is also moving onwards towards the west, in much the same manner as a coach-wheel goes round on its axle, whilst it is progressing from one milestone to another.

The course, however, which Cyclones steer (if I may be allowed the term) is not due west. In the West Indies, where they generally first appear somewhere to the east of Barbadoes, they take a course towards the W.N.W., or thereabouts, but gradually edge away more towards the north; and if they strike against the Peninsula of Florida, do not cross over it, but run along the coast, half on the land, half on the water, or, more commonly, altogether on the water. They thus frequently enough keep near the Gulf Stream, which Captain Maury and others have supposed to attract them by some unexplained influence: it seems more probable that the course of the two classes of phenomena—of the Cyclones and of the Gulf Stream—is due to one common cause, the direction of the coast line of the United States; and that Cyclones turn from the opposing nature of the continental air, as the oceanic stream turns from the one hundred fathom

* ADMIRALTY: Remarks on Revolving Storms, 1853, p. 7; see also the Tables, pp. 8, 9.

line of soundings; an opinion that is confirmed by the fact that when a Cyclone, passing to the southward of Florida, enters the Gulf of Mexico, it can neither cross the high land on the west, into the Pacific, nor the low land on the north, into the South-Western States,* but circles round, like a rat in a cage, and expends its energy in destroying the towns along the coast.

In the South Indian Ocean, Cyclones appear generally to rise between the Straits of Sunda and Mauritius, towards which last-named place they travel in a west-south-westerly direction, gradually edging southwards; and, as they approach the east coast of Madagascar, turn back somewhat towards the south-east. They never cross over the island into the Mozambique; and those few which, at rare intervals, rage in the channel, seem to be entirely local, and to extend no further.† Others, again, have been met with on the north-west coast of Australia: their course has not been exactly traced; and though they are said to follow the line of the coast towards the south-west, and to pass off into the ocean to the westward of North-West Cape, there is no satisfactory proof that they do.

In the Bay of Bengal they seem to rise a little to the west of the Andaman Islands, and to steer for the shore in a course varying from west to north. One season they destroy Madras, and roll, as it were, up the coast, laying waste every town and village they pass over; another season they break on Calcutta with the first of their fury; but there is no trustworthy account of a Cyclone, preserving its distinctive features, ever passing into the interior of the country.‡

In the Arabian Sea, and on the coast of Malabar, they are comparatively rare, and the direction in which they travel is by no means so constant as in other localities

* *Ante*, p. 29. † THOM: *Op. cit.* pp. 125, 164.

‡ PIDDINGTON: *Op. cit.* p. 54.

most commonly they keep nearly parallel to the coast line of India, but occasionally they seem to come in from seaward on a north-easterly course.*

In the China Sea they travel towards the north-west, and strike the coast near Hongkong, whence they sometimes go up the Canton River; at other times they go northwards, and occasionally fetch as far as the south-western shores of Japan. One that passed over Nangasaki, in August, 1858, placed the small squadron which was taking Lord Elgin to Jeddo in considerable danger, and forced it to shelter for a while in the Bay of Kagosima.

The course of a Cyclone thus appears to be determined, to a very great extent, by the direction of the prevailing wind—not of the wind which happens to be blowing at the particular time before the storm comes on, a wind that may be merely local and of very small extent, but of that wind which, as explained at length in preceding chapters, prevails in and forms a marked geographical feature of every known locality.

In the West Indies, for instance, the prevailing direction of the wind is easterly, veering very commonly, and more especially in the late summer months, to the south of east. Further north, on the coast of Florida, the southing at this season becomes more marked, and on the coast of Georgia the wind is for the most part from the west of south.†

It is exactly in accordance with this change in the *prevailing* direction of the wind that the Cyclones travel; first nearly due west, then W.N.W., continually inclining towards the north, and rolling up the American coast, or turning off into the Atlantic towards the north-east.

It is unnecessary to show, in detail, that these storms in the South Indian Ocean, and in the China Sea, also follow a line which markedly agrees with the prevailing direc-

* PIDDINGTON: *Op. cit.* p. 53, Chart III. † *Ante*, p. 25.

tion of the wind; whilst in the North Indian Ocean, occurring as they do at the Breaking of the Monsoons, their course may well be due to undetermined and irregular streaks of wind, modified to a very great extent by the coast line of Hindostan.

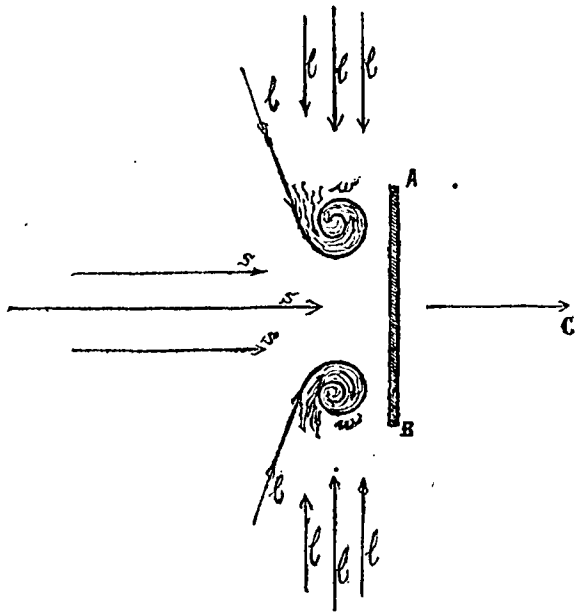
But apart even from the direction in which these storms travel, when we consider the localities and the seasons of the year in which they are met with, it is difficult to avoid the conclusion that they are directly caused by the intrusion of one current of air into another. The Hurricanes of the West Indies afford the clearest illustration of this. They occur in the months of August and September, seldom in July or October, and scarcely ever at any other time of the year.* They are never found to the southward of the parallel of 12° N.; at Trinidad, and on the coast of Venezuela, they are unknown. † It is between the parallels of 12° and 18° N., and, for the most part, to the east of the meridian of 60° W., that they take their rise; and an examination into the anemology of this locality during these months, shows that different currents of air are constantly meeting, and clashing one into the other, in a manner which must, according to the observed nature of fluids, produce a very great disturbance.

It is easy to see, in any pond, that where a stream forces itself in amongst the still water, it breaks into whirls of more or less violence; and if a large pipe, or conduit, discharges itself into a river, the result is the same. In this last case, the whirls are invariably in one direction. The stream from the pipe, meeting the obstruction of the water flowing nearly at right angles to the line of its own motion, turns back from it, as from a fixed barrier, and, naturally, towards the point of least resistance. It cannot easily turn up against the current of the river, for it is immediately beaten back; but downwards, the flow is con-

* *Ante*, p. 28. † ADMIRALTY: West India Pilot, vol. i. p. 3.

tinually dragging away the opposing fluid. The deflected stream, therefore, turns downwards, and circles back on itself; with no preference whatever, as to whether it describes such a circle from right to left, or from left to right, but always, *without exception*, commencing its whirl in the direction of the main stream and of the great body of water.

A very simple illustration of this may be given in a large tub, with a small piece of flat board. Holding this




board vertically, drive it through the water in a direction perpendicular to its plane. As described on a former page,* the water behind will rush forward in a strong, heavy stream, to fill up the hole which is made; but the water from the sides will also rush in, forming two comparatively small lateral streams, which invariably, as they

* *Ante*, p. 185.

meet the main following current, form themselves into two deep whirls, one on either side, each circling in a different direction, but each circling towards the board, and away from the pressure of the body of water behind. Thus, if AB represent the horizontal section of the board, forced through the water in the direction C, then the main body of the water behind will rush forward as shown by the arrows *s*; but on each side there will be the smaller lateral currents *l*, and the whirls *w*, turning always towards the board, as shown in the figure.

And when the South-East Trade, which in the Hurricane Months blows across the line far to the northward, and establishes itself permanently on the coast of the mainland, is driven by some accidental cause — some temporary, sudden, and excessive difference of temperature or humidity, or, however excited, some well-marked fluctuation of elastic force—into the great volume of the North-East Trade, in a part of the ocean where it has its full velocity, an atmospheric whirl is produced in exactly the same manner, and always turns away from the pressure of the main current of air.

In the illustrations which I have given of this whirling motion, it is easy to see the peculiar violence with which the circles form themselves. The water rushing round and round, as at *w*, does so with a velocity far beyond the rectilineal velocity of the currents *l* or *s*, from which it is derived; the moving water is, in fact, confined in a narrower space by the pressure of the continual influx from the back and from the side; the quantity of motion previously dispersed over a large area is concentrated. In air, the effect of a similar clashing of currents is the same; the velocity is intensified, but it is impossible, with our present knowledge, to say that to this cause alone is due the extraordinary and excessive velocity of the wind in a Hurricane; it is impossible to say how much of it is not rather due to

the electric action, whose manifestations are so terrific; how much to the enormous amount of condensation of aqueous vapour, and the influence which it exercises on the elastic force.

It is a well-established fact that, in the centre of a Cyclone, the barometer stands about *two inches* lower than it does outside the storm.* This is attributed to the air in rapid rotation being thrown outwards from the centre, in the same manner as a weight at the end of a string flies out from the hand round which it is whirled; but though it would seem certain that a great part of the very remarkable barometric depression is due to this action of centrifugal force, it needs only a notice of the violent rainfall which so frequently accompanies a Hurricane to show that other causes must exercise a considerable influence. Of the numerous logs collected by Sir William Reid, there is scarcely one which does not make direct mention of the heavy rain; and Mr. Thom calls still more special attention to it as one of the most constant and remarkable phenomena of Cyclones.† But great as the quantity of rain is, it is trifling as compared with that which falls continuously in the same time at Cherrapongee (in Khasia) in the height of the rainy season, or with that which is frequent at Cayenne, and other places along the north coast of South America—places where, nevertheless, the effect is not to produce Cyclones, or even violent winds; and we may therefore conclude that though the heavy rain does affect the barometer very sensibly, and largely increase the violence of the wind, its action is only secondary to that which is due to the rotation produced by the intermingling of the two great atmospheric currents.

With regard to the electricity which is manifested in such striking forms, there are no observations which enable us to say positively that it has anything whatever

* PIDDINGTON: *Op. cit.* p. 264. † *Op. cit.* p. 186.

to do with the motion; and it is maintained by many writers that it is produced by the storm rather than the storm produced by it—that the intense friction of the whirling air against air, sea, and land is sufficient to account for the phenomena which have been described. With this opinion I do not agree: the electric display, in its peculiar brilliance, not merely as lightning, but as fiery meteors,* is a distinctive characteristic of Cyclones presented by no other storms, even when the wind moves with as great a velocity, and grinds against the contiguous surfaces with as intense a friction; and, although proof is utterly wanting, it seems to me highly probable that the air of the North-East Trade and that of the South-East Trade, which is driven into it, are in very different electrical conditions, and that, as they endeavour to establish an equilibrium, the interchange between the two may, in some way which we do not understand, aid in producing the fierce whirl whose direction is determined by the direction of the previous rectilineal motion.

But whatever forces combine to diminish the elasticity of the air in the centre of a Hurricane, there is no doubt that the low barometric pressure is the direct cause of the Storm-wave, which breaks on every shore over which the storm blows, and does more damage by the inundation than even the wind by its excessive violence.† The water on these occasions rises sometimes to an extraordinary height; but there is probably an error in the statement that, at Santa Cruz, in the Hurricane of 1772, the sea swelled up 70 feet above its usual level.‡

The way in which the water is thus piled up is, to a certain extent, easy to understand. It results from the

* Reid: *Op. cit.* p. 30. † *Ibid.* pp. 70, 71, etc.

‡ Piddington: *Op. cit.* p. 192, quoted from the Annual Register for 1772.

hydrostatic principle of the suction pump, or of the barometer itself, as already explained;* and a Storm-wave, on a small scale, may be made, without difficulty, in a wash-hand basin. If the basin be quite full of water, and a tumbler, also full, be inverted over it, so that its edge just rests on the surface, it may be moved about to any position over the basin, without losing the water which it contains; but if it is moved beyond the side of the basin, all its water immediately falls out.

The enormous body of water which a Cyclone throws on to the land is, however, far beyond what can be held up by the excess of atmospheric pressure outside the storm; an excess which is, at the very most, less than three inches of mercury, or equivalent to about three feet of a column of water; and the extraordinary inundations which have been observed must be attributed, to a very great extent, to the horizontal driving of the water by the mere force of the wind.

I have dwelt specially on the Hurricanes of the West Indies, because we have a more extended and comprehensive series of observations of them than of any others; but wherever similar storms are commonly experienced, we find the same or somewhat similar anemological conditions, concerning which, indeed, we have frequently not sufficient information to enable us to form a definite opinion as to the exact way in which they act, but still sufficient to permit us to apply to them the lessons we have deduced from the phenomena of better-known localities.

The Cyclones of the South Indian Ocean occur always on the northern margin of the South-East Trade, which, from January to April,† draws back from the equator, and gives place to the North-West Monsoon. Streaks of this, forcing themselves into the great atmospheric current of

* *Ante*, p. 314. † *Ante*, p. 81.

the Trade wind, necessarily curl away towards the west, and generate a rotating motion in the direction of the hands of a watch.

The evidence which relates to the storms on the north-west coast of Australia, in what Mr. Piddington calls the Timor Sea, is extremely scanty; few have been recorded, and even of those, the notices are very imperfect. It is said, indeed, that they rotate in the same way as those near the Mauritius, because the general law has been laid down that Cyclones of the southern hemisphere always rotate in that way, and no exception has been observed; for a similar reason, it is also said that they pass off to the westward; but, in neither respect, has the rule in this locality been confirmed by actual proof. They occur only in the summer months, when the West Monsoon is at its strongest, and may possibly be formed by a gust of the wind which blows from the south and south-west, along the west coast of Australia and into the Timor Sea, being driven into the main body of air moving from the north-west. Whirls so formed would revolve in the manner stated; but it is difficult to understand how they can move towards the west, against the Monsoon, and, at present, there is no evidence which proves that they do.

In the Bay of Bengal they are rarely experienced, except at the change from the Summer to the Winter Monsoon, when gales from all quarters alternate with calms and confused weather. That such crossing and intermingling winds should give rise to Cyclones is quite in accordance with what we find in other localities, where the confusion is not so great; and the directions in which they revolve and travel may fairly be considered as pointing out that, at that particular season, the winds from south and east predominate sufficiently to determine the general course of the storm.

I have already called attention to the striking resemblance which exists between the Western Pacific and the

Western Atlantic, between the China Sea and the Gulf of Mexico, not only in the general formation of the coast line, but more particularly in the winds and the changes of the different seasons. The Typhoons and the Hurricanes of the two localities offer another point of comparison—they occur at the same time of the year; they travel in the same direction; and though Typhoons very commonly enter or confine themselves to the China Sea, they also frequently pass to the northward, outside the islands, and re-curve to the eastward,* in a manner almost identical with that of the well-known storms of the North American coast. I see, therefore, no reason to doubt that, in their origin, they are also similar; and that they are, for the most part, formed in the body of the North-East Trade outside, although they seldom come within the scope of European observation till they are near the coast of China.

It is beyond a doubt that revolving storms are also frequently met with in many other parts of the world besides those which we have just been considering; and some writers have gone the length of maintaining that all storms revolve, and do so in the direction indicated by the general law enunciated above.† This is stretching a favourite theory to an extent which is not warranted by observation; and the constant succession of westerly gales, which the mail steamers between New York and Liverpool experience regularly every winter, shows very clearly that they at least do not revolve. But when in mid-ocean an extraordinary wind comes from the north, driven down the coast of Greenland or through Baffin's Bay,‡ and forces itself into the great Westerly Atmospheric Current, a violent whirl is probably often caused, in exactly the same manner as a whirl is caused by the irruption of the South-East into the North-East Trade to the eastward

* PIDDINGTON: *Op. cit.* p. 58. † *Ante*, p. 337. ‡ *Ante*, p. 267.

of Barbadoes; and which, breaking away in the first instance towards the east, borne by the westerly wind, rotates from right to left. And again, when a south-westerly gale strikes the coast of Europe,—and the normal direction of our winter gales is from the south-west,—it strikes on a barrier of different and comparatively stagnant air; it curves away from it, necessarily towards the north, and circles back on itself, also from right to left.

The Law of Rotation holds, therefore, for all those storms which in our latitudes are forced in either of these ways to revolve. In other parts of the world the same coincidence is observed. Off Cape Horn, revolving storms are said to be common;* and though there is not—so far as I know—any distinct evidence of the fact, it does not seem improbable that the north-westerly wind on the coast of Patagonia is occasionally bent back towards the south and south-west; or that a sharp, strong jet from the southward bursts into the larger heavier current from the west, and is turned away towards the east. In either case the result is the same; the storm—and such a whirl in the air seems almost always to cause an increased velocity, or, it may be, it passes unnoticed if it does not—rotates from left to right according to the law for the southern hemisphere.

The same may be remarked about the circling of some Pamperos. The Pampero in its origin is certainly not a circling wind; it sweeps across the Pampas in a straight line from the south-west; and in those instances in which it rotates, it does so from the obstruction it meets with as it breaks into the northerly wind on the coast: it bends away to the southward, and rotates in the direction of the hands of a watch.

Amongst the many striking coincidences, points of resemblance or contrast to be noticed in the anemology of the different parts of the world, there is none more singular

* TOYNBEE: Met. of the N. Atlantic, p. 14.

than the regularity with which this Law of Rotation holds; a regularity which has induced many distinguished writers to attribute it to some covert action of electricity or magnetism, and has persuaded others that it is due to the rotation of the earth;* but whatever force their arguments may have, whatever additional velocity may be due to the causes alleged, the ordinary laws of the motion of fluids seem to me sufficient to account for every instance in which the Law of Rotation has been observed. And I would call attention to this; that if the direction of the rotation of storms, whether in the tropics or not, is determined by some fixed principle, such as the magnetic intensity or the rotation of the earth, that principle must act in every place and at every time. The earth is always going round; and if its rotation can direct the whirl of a Cyclone, it can also direct that of a dust storm in India or elsewhere: it can direct the dance of a pillar of sand and broken straws at the corner of a street, or the circling of an eddy in a river. We can see that on these it exercises no influence whatever: it is familiar to us all that dust whirls, whether on a large or small scale, turn indifferently to the right or left; that eddies in a stream are regulated by purely local causes, and turn as often one way as the other.

Nature makes no distinction between small and great: the drop of mist that lights gently down on a delicate flower, the avalanche that sweeps away a village, fall in obedience to one universal law: the tiny spark that flies out from the fire swells and moves subject to the same fixed rule as the vast masses that have towered to the heights of Sorata or Deodunga; and it would be subversive of the very first principles of physical science to admit that a whirlwind is released from the guidance of those forces which cause it to rotate in a certain direction as soon as its diameter becomes less than fifty miles. If

* REID: *Op. cit.* p. 508.—HERSCHEL: Outlines of Ast. p. 155.

it were possible to mark the gusts that drive up narrow streets, and, with constantly varying strength, meet at the corners, we should find that the little columns of dust which half madden us on a bright March day, are turning and whirling and dancing, not all in the same direction, but all in accordance with the law which, it is patent to every one, directs the eddies in the water, and which—I cannot doubt it—directs the fury of the Cyclones.

The law connecting barometric pressure with the direction of wind which has been proposed by Professor Buys-Ballot, and which is now generally known by his name, appears to be an extension of the Law of Rotation. It may be stated thus:—If there be a difference between the barometric readings at any two stations, the wind will blow *at right angles to* the line joining these two places, and will have the place where the reading is lowest on the left-hand side in the northern hemisphere, but on the right-hand side in the southern hemisphere.*

For strong winds, this law is—in our own latitudes at any rate—very generally true; and it is in accordance with it that the "Storm-Drum" is now hoisted at various stations round our coasts, whenever the barometric differences amount to 6-10ths of an inch.† Our attention is thus called to the fact that, in a very large proportion of our winter gales, the wind as it is driven in from the ocean turns back, more or less completely, on itself, and often with much increased velocity. That the low pressure of the centre of such a whirl is frequently observed before the strength of the gale comes on, may possibly be due to the onward motion of the air from the west, and the consequent addi-

* The observer's *back* to the wind.

† ROBERT H. SCOTT: An Inquiry into the Connexion between Strong Winds and Barometrical Differences [Report to the Meteorological Committee], 1868.

tional force of the after-part of the storm. It is often said that, in Cyclones, the strength of the wind, as it breaks out again after the central calm, is greater than ever: but where no real measurements can be made, and where everything is intensified by anxiety or alarm, no accurate judgment can be expected. Of the storms of our own coasts it has long been familiarly known that when the wind flies round from south-west to north-west, it does so with a gust of unusual strength;* and it will be easily seen that if the wind is rotating against the hands of a watch, such a change is exactly that which indicates the passing of the centre to the north. On the other hand, the comparatively few heavy gales that begin from south-east, are found almost invariably to veer through east, and to blow their hardest from north-east, after the centre of the whirl has passed to the southward. In such storms there are none of the peculiarities of Cyclones, except their revolution; and they appear to me—as I have said—to be merely the angry eddies of a strong current forced against a slowly yielding barrier.

In its fullest extent, however, the Buys-Ballot Law may be considered as—in our part of the world—embracing the whole system of the winds of the northern part of the Atlantic. The winds of the open ocean,—north-west, then west, then south-west; the south-west wind on the coast of Norway, turning very commonly through south to south-east towards its northern parts, and the north-east wind down the coast of Greenland, form, or appear to form, one large circle, round a district of low pressure in or near Iceland.† I have already partially traced what I conceive to be the causes of this circulation, and would attribute this district of low pressure and of variable winds to the

* GLAISHER: in Proc. of the Roy. Soc. vol. xiii. p. 19, etc.; see also *ante*, p. 23.

† BUCHAN: *Op. cit.* pp. 217, 218, and Plate II.

friction of the atmospheric currents which pass by it on different sides, and continually carry away large quantities of its air. Whether this is the true reason or not may be doubted; but to say, as some writers have said, that these winds are caused by the low pressure there existing, and that they blow round it as they do because the Buys-Ballot Law requires them to have the place of low pressure on the left hand, seems to me to be a confusion between cause and effect. The Buys-Ballot Law is simply a statement of observed fact, the general truth of which may be readily tested by a week's study of the weather reports in the *Times*; it is purely empirical, and, far from being considered as affording any explanation of anemological phenomena, can rank only as an ingenious and succinct description of a certain class of them.

From the earliest times it has been a practical rule amongst seamen that when, in any place, there is a shift of wind, that shift is commonly towards the right in northern latitudes, and in southern latitudes towards the left. Professor Dove has named the statement of this familiar fact THE LAW OF GYRATION,* and has devoted the labour of many years to a scientific investigation of it. He considers that the veering of the wind in accordance with this law results directly from the influence of the earth's rotation. His argument amounts to this: that if a large volume of air is impressed with a movement towards the equator, the several particles of it, as they pass over any specified place on the earth's surface, arrive from places successively more and more remote; that their absolute velocity *towards* the east, due to the rotation of the earth on its axis, is thus continually diminishing; their relative velocity *from* the east is continually increasing, and the

* At least Mr. Scott, in his authorized translation of the Law of Storms, has so rendered "das Drehungsgesetz."

direction of the wind becomes continuously more and more easterly: and conversely, that if the movement is towards the poles, the direction of the wind becomes more and more westerly.

On previous pages I have examined, at length, into the influence which the rotation of the earth exercises on the direction of currents, whether in the atmosphere or in the ocean, and have shown reasons for believing that it is extremely trifling. Even were it not so, the theory that would refer to it the Law of Gyration, is liable to the objection that, whilst the influence of the earth's rotation is constant, unceasing, and unchanging, the Law of Gyration, though true in a large majority of instances, is not true universally; the exceptions to it, both in strong winds and in light breezes, are very numerous, and seem to me to afford conclusive proof that the wind, in its veerings, is totally independent of a cause so uniform and unalterable. On the other hand, the fact that a wind revolving in accordance with the Law of Rotation, and swept on continuously towards the east, will, as it passes over Northern Europe, veer, in places south of its centre, from south-west, through west to north-west, renders it probable that the Law of Gyration is dependent on the circling of the atmospheric eddies: and the very noticeable tendency of the wind to veer in this direction seems to point out that, in ordinary circumstances, the centre round which it tends to rotate lies far towards the north; but that when the wind has greater strength, and forms itself into a violent whirl, the whole of which it describes in temperate latitudes, the gyration in the southern part of the circle is still according to the law stated, in the northern part is contrary to it. Instances of this last would seem to be exceptional: in the experience of seamen this reverse motion is comparatively rare, and is generally associated with storms of

unwonted fury, which have thus given a proverbially bad name to winds that *back*, or veer against the sun.

To go more at length into this particular application of the influence of the rotation of the earth, would be merely to repeat the objections which I have already brought forward. The curious instances of the veering of the wind in accordance with this law, which would seem to be so regular in certain localities,* and which Professor Dove considers as strongly supporting his views, appear to me to be simply whirls into the comparatively still air of the central district of each oceanic basin. Whether this is so or not, cannot, at present, be absolutely determined; although the known habitudes of fluids in motion,—the very first principles of experimental hydrodynamics,—lend a strong support to this opinion; but it would be contrary to all direct evidence to admit that the rotation of the earth produces any sensible effect on that motion of the air which we call WIND.

* *Ante*, pp. 55, 86.

## CHAPTER VIII.

### THE INFLUENCE OF THE HEAVENLY BODIES.

AIR is a fluid which—so far as we know—is peculiar to the earth. Whether it is to be regarded as, in any way, an emanation from the earth, a species of terrestrial vapour, or not, is a point altogether beyond the subject of our present inquiry. Our interest in this place, is confined to the fact that, whatever its origin, no trace of its existence has been discovered in the distant realms of space. Held down to the earth by the force of terrestrial gravitation, it is variously estimated as reaching upwards to a height of 50, 100, or 150 miles. That it does not reach beyond that, appears to be satisfactorily established by observations of astronomical phenomena, of occultations of stars, and especially of the eclipses of Jupiter's satellites.

Air, similar to our own, in the neighbourhood of Jupiter, would be drawn in, collected, and compressed, by the force of the planet's attraction, to a density which, at a clear distance of more than half its radius would equal, and at the surface itself would be about 3·5 times that of our atmosphere at the surface of the earth. The refraction produced by air so compressed would be very great, and easily observed; the fourth satellite would, during its eclipse, be visible on both sides of the planet at the same time.* We know that this is not so: and the fact that it is not so, proves that Jupiter, at any rate, has not an

* Dr. WOLLASTON: in Phil. Trans. 1822, p. 89.

atmosphere such as ours. Atmosphere of a different sort, and of a totally different refractive power, it may have; it probably has; but if so, that atmosphere is confined to it, in the same way as ours is confined to the Earth, or as the Sun's is confined to his own immediate neighbourhood. The recent observations which tend to show that the Sun has a very extended atmosphere consisting of nearly pure hydrogen,* seem to give us a clue to an explanation of the possible existence of other atmospheres with widely different powers of refraction.†

This, however, is beyond our purpose; but once establishing the fact that air is a substance of the earth, extending only a limited distance from it, we open a field for inquiry as to whether the forces of celestial attraction, which we know act so powerfully on every member of the solar system, and on every astral body, even the most remote, do not produce some effect also on its extremely elastic and mobile particles.

It has, in all ages, been commonly maintained that the influence of the moon on the weather is very great, and there are popular sayings, in every language, which express this general opinion. These, for the most part, refer to the full or new moon; and the change of the moon is everywhere spoken of as likely to bring with it a change of weather or wind. This is the general belief of sailors, a

* Prof. H. E. ROSCOE: Spectrum Analysis, 1869, Lecture vi.; see also W. HUGGINS: On a Temporary Outburst of Light in a Star in Corona Borealis, in Quart. Journ of Science for 1866, p. 381.

† Refractive indices of different gases:—

(Vacuum 1·000,000).

| | | | |
|---|---|---|---|
| Hydrogen . . . | 1·000,138 | Nitrogen . . . | 1·000,300 |
| Oxygen . . . . | 1·000,272 | Carbonic acid . | 1·000,449 |
| Air . . . . . | 1·000,294 | Chlorine . . . | 1·000,772 |

For the Limits of Vaporization, see FARADAY, in the Journ. of the Roy. Inst. of G. Brit. vol. i. p. 70.

class of men who, whether learned or unlearned, scientific or ignorant, are singularly observant of phenomena which affect their comfort, their well-being, and their safety; it is the belief of shepherds, hunters, and husbandmen, all over the world; and whilst, on the one hand, a very great number of eminent meteorologists endeavour to prove statistically that it rests on no foundation of fact, I, for my part, place more reliance on the simple practical statements, to be found in almost every Sailing Directions,—that foul weather, or a change of weather, or a shift of wind, or some noticeable peculiarity may be expected at "full and change."

But it is impossible to suppose that any effect which the moon produces can be brought about merely by the different quantity of heat and light which she gives forth. Sir John Herschel thinks, indeed, that the heat emitted by the full moon has, to a certain extent, the power of dispersing clouds, that is, of re-vaporizing the partially condensed moisture of the upper atmosphere.* The amount of heat we derive from the moon is exceedingly small; the most skilful arrangement of the most delicate instruments is necessary to render it appreciable; and although a large portion of the heat must be absorbed in its passage through the strata of air, it is at least questionable whether the quantity of heat from the moon, which arrives even at the highest clouds, can be sufficient to produce any noticeable effect; whilst the clouds which form the dark mantle of night, are, as a rule, low-lying, or at a height not exceeding 5,000 feet above the surface of the earth. But indeed the effect claimed for it is itself very doubtful; rests on merely a small majority out of a large number of observations; and, if established, is of extremely trifling importance.

Many modern meteorologists have, therefore, endeavoured

* Familiar Essays on Scientific Subjects, p. 147.

rather to trace a connection between the weather and the moon's movement in her orbit round the earth. Observations continued through many years seem to establish the fact that there is such a connection, but we are still ignorant of the way in which it acts; it is, however, tolerably certain that the changes in atmospheric pressure are, to some extent, influenced by the moon; the Greenwich observations determine that the barometer stands, on an average, higher when she is in north declination than when she is in south; that it rises as the moon travels north, and falls as she returns towards the south.* Other barometric variations have been observed, which appear to be, in some way, dependent on the moon's distance from the meridian, and which have been considered as indicating a motion of the air analogous to the semi-diurnal piling up or withdrawal of the water of the ocean, known as the flow and ebb of the tide.† These differences of pressure are, however, very small, and being masked, or overpowered by a hundred trifling meteorological changes, —changes in temperature, or humidity,—they require a long series of observations to establish them as positive facts. They are thus clearly inadequate to produce any strong or distinctly marked effect on the movements of the air; but they may, perhaps, serve to call our attention to the force which does produce effects of the greatest importance.

The existence of both daily and monthly aërial tides, is, as I have just said, established by a long-continued series

* In 1846, for example, the mean height of the barometer when the moon was—

| | Inches. |
|---|---|
| At or near her greatest N. decl. was . . . . | 29·8254 |
| On or near the equator, moving southwards . . | 29·7549 |
| At or near her greatest S. decl. . . . . | 29·6459 |
| On or near the equator, moving northwards . . | 29·6853 |

[Abstracts of Results of Met. Obs. p. 123, in Greenwich Mag. and Met. Obs. for 1846.]

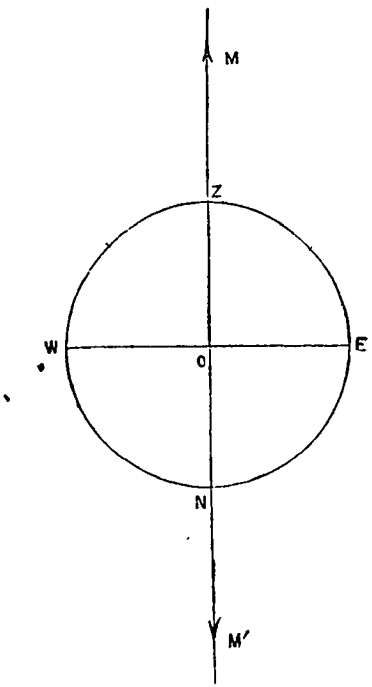
† P. E. CHASE; Aërial Tides; Proc. of the Roy. Soc. vol. xiii. pp. 329 *et seq.*

of barometric observations; but these observations show such an extremely small difference of pressure, that it has been very generally concluded that the amount of the tide is also extremely small, and that the effect of the moon's attraction on the air is utterly insignificant. In forming this conclusion, one point appears to have been overlooked: it is this—that the piling up of the air over any one place does not necessarily imply an increase of atmospheric pressure at that place. The general idea seems to have been that it does; that the height of the barometer measures the weight of the air, and depends entirely on the length of the atmospheric column. But if a column of air is forcibly held up—as by lunar attraction—its weight does not press on the surface of the earth, or of the cistern of the barometer. I may hold a lump of lead over, and even touching one of the scales of a balance; but this lump of lead will in no way alter the relative position of the scales, so long as my hand supports the whole weight of it; and if my hand is incapable of doing so, or does not do so, the scales will show, not the weight of the lead, but the excess of that weight over the power which I am exerting. It is so with this lunar attraction; it holds up, and is capable of holding up, a certain increased column of air; it is only when the air, set in motion towards that point of greatest attraction, streams in, in excess of what the attraction is capable of supporting, that any increase of pressure is felt on the surface of the earth. The barometric differences daily shown are, in a faint degree, and allowing for the sluggishness and insensibility of the instrument, the measure of this excess; but they do not, in any way, afford a measure of the depth of the aërial tide, or assist us in forming an estimate of the extent to which such a tide causes a movement in the free and unbounded expanse of the atmosphere.

We may, however, consider the minuteness of these differences as pointing out that the height of any tide,

which may exist in the atmosphere, must be caused almost entirely by the direct pull of the moon, or other attracting body; as showing that there is no piling up of air, on any grand scale, due to opposing barriers, or conflicting motions, such as we see daily take place in the waters of the ocean.

To distinguish between the several forces which tend to produce these effects, it will be necessary to explain, at




some length, the manner in which the moon, by attraction, acts on the atmosphere; and in order to do so more simply, I will, for the present, suppose her to be fixed in space, in the plane of the earth's equator, and the earth to revolve on its axis at some certain distance from her.

Let the circle, WZEN, represent the equator of the earth, revolving on its centre O, from W to E, in the direction of the hands of a watch, as indicated by the letters; and let the attracting force which the moon exerts on the earth be denoted by M. This force is the aggregate of an infinite number of minor attractions, which act on every particle of the earth's volume, in directions which really converge to the moon's centre, but which may, for our present purpose, be considered as approximately parallel.

The resultant of all these, that is, the force M, acting at the centre of the earth, necessarily tends to draw the earth towards the moon. As the earth does not move towards the moon, this force is evidently counterbalanced by an equal force tending to draw it in the opposite direction. This is the most elementary proposition in Statics.

An exact explanation of the nature of this force would involve mathematical considerations which belong rather to the province of Dynamics, or Physical Astronomy. It will be enough to say that it results from the action of a force similar to that which tends to break the string by which a weight is being whirled, which holds the water in a bucket when it is swung round quickly and evenly, or which binds the car safely to the rails at the highest point of a centrifugal railway. The earth is—it may be considered—held in its orbit round the sun by the joint action of gravity and centrifugal force; by similar forces the moon is held in her orbit round the earth: thus constrained to move, each in its own path, the earth and moon are unable to yield to that mutual attraction which would cause them to clash together; and the effect on each is as if a force, equal to the attraction of the other, were pulling it in exactly the opposite direction; the effect on the earth is as if another moon—or as it is frequently called an

anti-moon—were situated in space at the same distance as, and diametrically opposite, to the real one.

Let M′, acting on the earth's centre, denote this force, which, in the same manner as the direct attraction, may be considered as the resultant of an infinite number of components acting on every particle of the earth, in directions which, as before, may be considered as parallel.

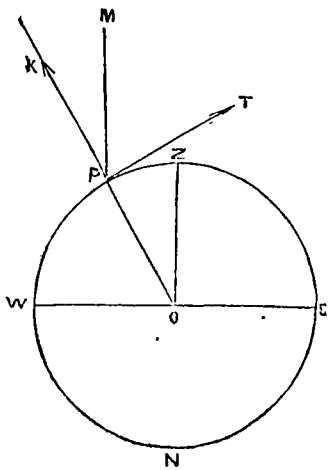
But though the opposing forces M and M′, acting on the centre of the earth, are exactly equal to each other, the several opposite components acting on individual particles are not so. The force of gravitation increases as the distance of the attracting bodies diminishes, and diminishes as the distance increases; to speak accurately, it varies inversely as the square of the distance. The attraction of the moon, on a particle at the centre of the earth, is therefore less than it is on one situated at the nearest point of the surface, as at Z, and greater than on one at the farthest point, as at N; and the forces of attraction are greater on particles situated along the circumference, WZE, than on particles on the circumference, ENW. On the other hand, the forces of repulsion, — of the attraction, as we may regard it, of the anti-moon,— are greater on particles situated on the circumference, ENW, than on WZE, and are greatest at N, least at Z.

Thus, then, for every particle on the circumference, WZE, the force of attraction acting on it is greater than the force of repulsion also acting on it; and for every particle on the circumference, ENW, the force of repulsion is greater than the force of attraction. The particles on WZE, have therefore a certain tendency to move in the direction M; and those on ENW, a corresponding tendency to move in the direction M′; a tendency which is greatest at the points Z and N respec-

tively, and which vanishes on both sides at the points W and E.

A free particle resting on the earth at either of the points, W or E, is thus, so far as regards these forces of attraction or repulsion, in equilibrium; but at every other point, it is acted on by the excess of one or the other, so as to be drawn away in the direction of either M or M'.

If, for example, the particle is in the position P, it is drawn towards M by a force which actsg alon the line




PM, and which may be resolved into two forces, acting respectively along the Normal and Tangent, in the directions PK, PT.

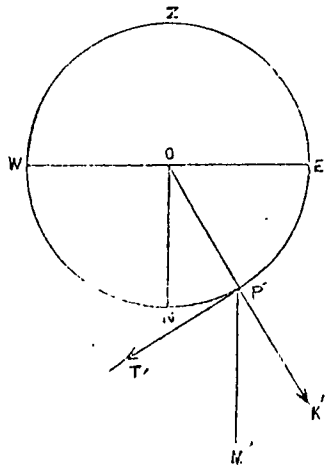
The Normal force gives the particle P a tendency to move away from the earth's centre, a tendency which continually increases as the particle moves from W to Z, where it is at its greatest, being then caused by the whole force of the moon's attraction. The actual motion, however, resulting from this tendency, is inconsiderable, owing

to the attraction of the earth, which draws with overwhelming force in the opposite direction.

To the Tangential force there is no counterbalance. From the moment that the particle leaves the position W, this force acts without opposition; if the particle at W is, relatively to the surface of the earth, at rest, this force, so acting, generates, and continues to generate velocity, in the direction PZ. It has its greatest value when the particle is half-way between W and Z; that is, when the angle WOP is 45°; but although it decreases from that greatest value to nothing, at Z, it is throughout the whole quadrant unresisted, and the velocity, being continually increased, attains its maximum as the particle passes Z. The tangential force is then reversed; it becomes a retarding instead of an accelerating force; it checks the velocity of the particle instead of increasing it: but the intensity of the retarding force is exactly the same as that of the previous accelerating force; and to reduce the velocity to zero from the maximum which it had at Z, the retarding force must act for the same length of time as was necessary for the accelerating force to generate that velocity. This was the time of the passage of the particle from W to Z, or, in general terms—the moon being supposed stationary—and neglecting the shortening of the interval by the independent motion of the particle towards Z, was a quarter of the period of the earth's revolution on its axis—that is to say, about six hours. During the following six hours, therefore, which the free particle takes to pass from Z to E, it has an independent motion towards E, and a velocity which, though continually diminishing, does not vanish till the particle reaches E, where it is again in a state of rest relative to the earth's surface.

But as, in the continuous revolution of the earth, the particle passes through E into the quadrant EN, to a position as P', it is acted on by the excess of the force

of repulsion over the force of lunar attraction, and is drawn away in the direction M'. This force, as before, may be resolved into the components along the normal and tangent; and, as before, whilst the opposed and restrained normal force produces a slight and almost imperceptible motion away from the earth's centre, the tangential force is left unopposed to produce its full effect in generating a velocity in the direction P'N; this velocity is at its maximum as the particle passes N, when the action of the tangential force is reversed, and begins to check the velocity, gradually reducing it to zero at W. Here, as before, the



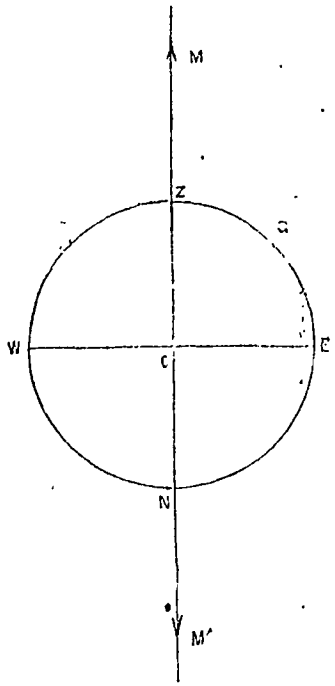

particle is, relatively to the earth's surface, at rest; and from this point gradually gathers a new velocity towards Z. The attraction of the moon must thus give to every free particle near the surface of the earth, which belongs to the earth, and is carried round with it in its diurnal revolution, a certain tendency to move in the same direction as that in which the earth revolves—that is, from west to east; if only it can be admitted that, at the points of quadrature—that is to say, at the points W and E, where the

disturbing force of the moon vanishes—the particle being in equilibrium, is also at rest relatively to the surface of the earth. If this is so, if the particle is at these points of quadrature relatively at rest, there is a distinct force acting on it, producing this tendency, which is entirely unopposed; and, however small the force may be, a perfectly free particle must yield to it.

It is, however, not only the moon that exercises such a force. The attraction of the sun on each particle of the earth is many times greater than that of the moon; and though, by reason of his vast distance, the difference in the force, caused by the difference in the distance from him of the several points on the earth's surface, is much less than the corresponding difference in the attraction of the moon, the enormous magnitude of the total force renders it still very considerable. And besides the sun, every heavenly body exercises its own influence. Every planet, every asteroid, every star, every atom floating in space, however minute, however distant, adds its individual attraction, and, to some extent, infinitesimally small though it may be, increases this differential force which, mainly due to the attraction of the moon and sun, pulls on every particle on or near the surface of the earth, and gives to every particle free to move, an independent motion from west to east.

There can be no doubt of the existence of the disturbing force which I have here described; but the assumption on which I have, to a great extent, based this account of the tendency, and actual independent motion from west to east, may fairly be disputed; and, in treating of any natural phenomena, cannot be maintained without some evidence of its truth or of its probability. This assumption is that the particles under consideration are at rest, relatively to the surface of the earth, at the points of quadrature; and though it may, in a loose and vague manner, seem likely enough that the points where the

disturbing forces balance each other, are the points of rest, it seems, perhaps, as likely that they are rather the middle points of alternate oscillations; and this, indeed, is the generally received opinion; in accordance with which it is held that the points of rest are the points of the octants, 45° each way from the points of quadrature.




According to this view, a particle starting from relative rest at F, a position halfway between W and Z, and acted on by the disturbing force already explained, moves towards Z, and passes Z with a maximum velocity due to the time taken in describing the octant FZ, which carries it, against the retarding force, through the succeeding octant to G, where it comes to rest. An opposite motion is then generated, and the particle is whirled past

E with another maximum relative velocity, in a direction from E towards Z, which it carries through the next octant. The motion then again changes and continues to change; the points immediately under or opposite to the moon, and the points of quadrature, being points of maximum velocity in opposite directions; the octant points being points of relative rest. A particle moving in this manner will preserve, during the whole revolution of the earth, the mean *absolute* velocity of a point rigidly connected with the surface; a circumstance to which—it seems to me—undue weight has been attached; for if particles, restrained by gravitation to a certain distance from the earth's centre, are free to move relatively to the earth's surface and to each other, and do actually move, it cannot be of any serious importance, so far as the dynamics of the particle are concerned, whether that motion is an oscillation, bringing the particle back to the point from which it started, or not. I proceed, therefore, to inquire into the effects which each of these movements would produce, and, so far as our present observations render possible, to examine into the effects which actually are produced.

But the particles on the surface of the earth, of which we have any cognisance, are by no means free: the particles of water in the open ocean are the most so; but even they are held together by a very considerable force of cohesion. Notwithstanding this, and notwithstanding the force of gravity which binds each particle to the earth, the variation to which the sea level is subjected by the influence of the normal force, of which we have spoken is familiar to us all. Under the most independent observable circumstances, in the middle of the Pacific, this variation amounts to a mean rise of about nine inches. It has, indeed, been theoretically estimated at more than double that; and there seem to be satisfactory grounds for

the opinion* that the smallness of the observed as compared with the calculated result, is due to the yielding of the quasi-rigid bodies, to a *tide* in the solid mass of the earth itself; which thus, causing a rise in the land simultaneously with a rise in the water, lifts up the standard marks to which differences of level must be referred, and makes them appear less than they really are.

Such a force may seem trifling in comparison with the almost infinitely greater forces which are regulating the grand movements of the universe. Its effect on the surface of the earth is slight in its absolute amount, insignificant in its cosmical relations; but it is stupendous as compared with the effects of those terrestrial forces which we are accustomed to consider the most terrible and magnificent. When the igneous force, which—whatever its origin—lies buried deep within the earth, in an occasional effort heaves up a small portion of the surface, through a height of a few feet, agitating it violently by reason of its spasmodic nature, the world stands aghast in awe and admiration. The force, which we have been considering, is each minute of every day performing a mightier task; is doing more work; is gently lifting a far heavier weight over a much larger area, and is holding it sustained until the due time arrives for it to lay it down again. It is as a strong man carrying with ease a burden which a weaker one, lifting with a jerk, lets fall again immediately with crash and uproar.

An effect so great as this upheaval of the earth's surface, this actual raising of these huge solid masses through a vertical height of between one and two feet, hourly going on, gives us a more vivid conception of the enormous magnitude of this normal component of the celestial dis-

* THOMSON and TAIT: Treatise on Natural Philosophy, vol. i. §§ 832, 846.

turbing force; and enables us in some degree to estimate the value of that other component, whose intensity we have no direct means of gauging.

We can, however, be quite certain that the aggregate of the tangential forces is much less than that of the normal. But in its action on the particles of water in the sea, this tangential force is unopposed except by the friction and cohesion between the particles themselves; and the sensible result which it produces,—the motion it causes, is much greater than that caused by the more intense, but counterbalanced normal force, which in the open ocean does not raise the level of the water more than about nine inches. Observations on this point are neither numerous nor exact, but they all agree that on the shores of small islands far away from any mainland, the tidal rise and fall is very trifling, and unlike that which we witness on many parts of our own coasts. This great difference is due to the action of the tangential force, which, drawing the water bodily to the eastward, throws it with a dash on the eastern boundary of the sea, the west coasts of the continents, against which it rises to the height of several feet. The advance of the water is stopped by the land; the velocity is destroyed by the impact, and the tangential force, beginning to act in the opposite direction, drags the water away from the western coasts, and throws it against the eastern, on the farther side of the great Ocean. Not that the tides on opposite coasts are to be understood as exactly supplementary to each other; but when the one velocity is destroyed, the reversed force, instead of merely acting on the moving water as a drag, is able to generate a new velocity in the opposite direction.

This motion of the sea is frequently spoken of as the advance or retreat of the tidal *wave*, a manner of speaking which is quite in accordance with popular usage, but which sometimes gives rise to a strange confusion of

ideas. A wave is a pulsation amongst the particles of a fluid, a vibration which tends to break the internal cohesion, which, within certain more or less narrow limits, causes the whole mass alternately to swell and contract, but which produces no effective change of locality. It cannot, therefore, be strictly understood as meaning the bodily translation of a very large mass of water from one place to another. When a bucketful of water is drawn hastily from a pond, the agitation produces a well-marked series of waves which continue for some time; but the rush of water into the hole is no more a wave than is the upward movement of the water in the bucket; and the enormous volume of water, which twice in every twenty-four hours rolls up the English Channel and dashes itself against all our shores, is no wave, but an actual and important movement of a large body of water, a fact which will not easily be forgotten by any one who has had to ride for his life on the flat sands of the Solway Frith or of Morecambe Bay; the rush of water through the Solent—the narrow channel between the coast of Hampshire and the Isle of Wight—is as real a motion of translation as the stream of the Thames or of the Severn, as the Fall of Niagara or La Guayra.

It is where a body of water so moving enters a funnel-shaped and gradually contracting channel, and from the sheet-like form which it had at the entrance, becomes piled up into a thick mass, that we find tides of exceptional height. To this are due the high tides of the Bristol Channel—tides which commonly rise as much as 30 or 40 feet, and attain a height of even 70 feet in the neighbourhood of Chepstow, where a part of the incoming water is checked and driven into the Wye. In the Bay of Fundy a somewhat similar formation of the coast occasions similar tides of extraordinary height; a rise and fall of 120 feet is said to have been observed in the neighbour-

hood of Annapolis; and without laying too much stress upon these extreme instances, the phenomena of remarkably high tides in many very different parts of the world are probably familiar to most of us.

The force that produces these excessive results, by its action on the sea, acts also continuously on the atmosphere, and must produce some corresponding effect. As it acts on every particle of the air in exactly the same way in which it acts on the water, and is restrained still less by the mutual cohesion of the particles, we are not at liberty, without very strong positive evidence, to suppose that the effect on the atmosphere can be inconsiderable: all analogy, every consideration of the nature of the two fluids, tends to show that the effect on the mobile atmosphere must be far greater than on the comparatively inert waters of the ocean. If, then, this tangential force, constantly acting on the atmosphere, generates a motion such as we find it generate in the sea, differing only from that by its greater velocity, such a motion must, *in some way*, manifest itself to us; if permanent, by the permanent flow of the atmosphere in one constant direction; if alternating, by a regular alternation of the atmospheric currents, and by an increase of barometric pressure when such alternating currents clash.

I have already pointed out that the height of an atmospheric tide caused by the direct attraction of the moon—that is to say, by the normal disturbing force which we have been considering—cannot produce any important effect on the barometer; but if a current, generated by the tangential force, is opposed, so that the air piles itself up into masses resembling the masses of water which we see piled up on the continental shores, the barometer will necessarily show the increased pressure which results from the increased weight of the atmospheric column, in exactly the same way as the pressure on the bottom of the Bay of

Fundy must be increased, when water is piled over it to an additional height of 100 feet. That the barometer bears no witness as to any such regular increase of pressure,—shows no trace of any such violent atmospheric tides, would seem to warrant us in forming the conclusion that such tides do not exist, and that there is no clashing together of the atmospheric currents caused by the tangential force.

But it is difficult to conceive these currents alternating or oscillating without a continual interference with each other. The motions generated by the disturbing forces of the moon, the sun, each separate planet, and each individual member of the starry host, will necessarily be all different, and will, at any given time, have different centres of oscillation: the interference which must ensue, is exactly that of which we find no trace. This alone is very strong evidence that there are no such alternations; but stronger even than this, is the utter want of any observations which would support the theory of their existence by positive testimony. It is perfectly clear that if the currents of air oscillated in a series of alternate rushes from west to east, and from east to west, our observations of the upper currents could not show, as they do,* a permanent flow in one direction.

When, then, we consider that all observation does show that the air of the upper atmosphere moves permanently and continuously from west to east; that very detailed examination of the prevailing currents of the lower atmosphere points out the same continuous tendency as the very probable origin of all the principal variations;† and that this continuous flow would clearly render any interference or clashing, and consequent *tidal* increase of barometric pressure almost out of the question,—we find, independently of other considerations, a body of evidence

* *Ante*, chap. i, section viii. † *Ante*, chap. v.

in support of the assumption which I put forward on page 369, which is not lightly to be set aside. To me it seems conclusive, as establishing the point, not indeed with mathematical certainty, but with a very high degree of probability.

Leaving, however, on one side the manner or direction in which this tangential component of the celestial disturbing forces acts, and ignoring the deductions as to its importance which are offered by the effect which it produces on the waters of the ocean, it is very commonly maintained that the force is altogether inadequate to produce any noteworthy effects on the atmosphere. This idea has been founded on an arithmetical calculation which shows the numerical value of the force as exceedingly small; so infinitesimally small, that any motion in the air must—it is presumed—be due to the incomparably greater effect of difference of temperature. As briefly as possible, I will examine into this calculation.

The mean temperature of the oceanic air in the equatorial regions is estimated at about 82° F.; the mean temperature near the parallel of 30° may be taken as 71° F. [82°. cos30°], that is to say, between the two there is a difference of 11° F. But to meet the most extreme view of the case, let us suppose that there is a difference of 30° F., or a degree of temperature for each degree of latitude. The expansion of air is approximately ·002 of its volume at freezing point for each higher degree of Fahrenheit's scale. A unit of volume at freezing point will therefore have, at the temperature of 71°, a volume 1·078; at 72°, a volume 1·08; at 73°, a volume 1·082; and so on. These give the respective densities—that of the air at freezing point being unity—·92764, ·92593, ·92422, etc., or a difference in density for one degree of latitude—that is, for 60 miles, of ·00171.

This is equivalent to a difference in density,
for one mile of latitude, of ·0000285;
for one yard of latitude, of ·00000001425; and
for one inch of latitude, of ·00000000036.

We might easily go on to still smaller fractions, but this is, perhaps, small enough to illustrate my meaning.

Let us, then, consider two contiguous cubic inches of air lying along a meridian somewhere near the parallel of 30°. Each of these is pressing against the other with a force denoted by its density, and the denser of the two drives back the less dense; that is to say, a difference of density of ·00000000036 is, according to the usual supposition, sufficient to cause one small volume to drive another volume of equal size towards the equator at the rate of about twenty miles an hour.

If, instead of taking an inch as the unit of length through which the density is constant, we consider—as is theoretically the case—the density to be varying with each infinitesimally short distance, the difference between the densities of successive particles is inconceivably small, and may be written with hundreds, or thousands, or millions of cyphers after the decimal point. There is absolutely no sensible difference of pressure which, transmitted from one to the other, can cause a sensible motion; although, as a difference does really exist, it produces also a motion which in former chapters, I have spoken of as an insensible or imperceptible circulation amongst the particles of fluid.

The error of attributing any noticeable effect to such a cause has arisen from considering the difference of the densities at the two extremities of the line. It has been said that differences of 10°, 20°, or 30° of temperature were equivalent to differences in density of ·01686, ·03207, or ·04874 respectively; differences quite sufficient to account for effects much more violent than were observed.

It has been lost sight of that a particle of air in latitude 30° does not press against a particle of air in latitude 10°, but against a particle of air in latitude 29°·9; and it is to the difference of density between these two particles that any motion which arises there must, on this hypothesis, be due.

On the other hand, the greatest disturbing force which arises from the difference of the moon's attractions is ·0000002112 of the force of terrestrial gravity at the surface of the earth: that arising from the attraction of the sun is ·0000001029, giving a total disturbing force of ·0000003141 of the weight of the particle acted on. The greatest relative value which the tangential force can have is, therefore, about ·00000016, a force which is certainly extremely small, but is, nevertheless, almost infinitely greater than that with which, from gradual difference of temperature, the contiguous particles of air press on each other.

This, then, is the view of the subject as shown by arithmetic. But strong as is the evidence of the figures as to the enormous preponderance of the force of attraction over that resulting from differences of temperature, fractions so exceedingly small as those I have been writing down cannot be considered as conveying any decided impression of magnitude or of comparison: it was necessary for me to show that the most exact of sciences is entirely in favour of the opinion I have put forward; but, having done so, I prefer resting that opinion mainly on geographical evidence, and maintaining that a force which is able to drag vast masses of water up various arms of the sea against an intense friction, and to pile them up on high, in opposition to the action of gravity, is also able to drag along the far freer and more mobile masses of air, even with a velocity equal to that of the continuous gale which blows over the highest mountain tops, whether over

the Rocky Mountains, or the Southern Andes, in the temperate zones, over the Peak of Teneriffe on the tropical circle, or over the Camaroons near the equator.

With our present knowledge, it is impossible to say positively that it is this disturbing force of celestial attraction which produces the effects described; but when we find a general set of the air from west to east, which, as we ascend and escape from the confining influences of the earth's surface, becomes both stronger and more constant; when we find that this current is irrespective of differences of temperature and humidity, streaming alike from localities hot or cold into others cold or hot; alike from moist into dry, or from dry into moist; that it is uniformly maintained, independent of all the observed meteorological conditions with which our daily registers are crowded; when, in fact, after careful search, we are unable to find any terrestrial agency which even tends to produce such a current, but do find a celestial force, which, notwithstanding its reputed infinitesimal nature, is, within our own direct knowledge, capable of producing very extensive movements in the ocean, and which, acting in a similar manner on the air, may, under certain probable conditions, generate motion in the direction of the observed current, we establish a strong basis for the belief that there is between the two the connection of cause and effect; that the force, which we have been considering, causes the aerial current; that the westerly wind, prevalent at the surface of the earth in the temperate zones, frequent on or near the equator, almost constant in the upper regions of the atmosphere, is the effect of the action of the heavenly bodies, and, pre-eminently, of the sun and of the moon.

In the explanation which I have given of this force, I have supposed the heavenly bodies to act in the plane, or parallel to the plane of the equator. To enter on the subject in greater detail, to attempt to form an estimate of

the effects produced by the changes of declination of the sun and moon, could scarcely, in the present state of our knowledge, lead to any satisfactory result. We know, indeed, that about the time of the equinoxes, violent storms are common all over the world; storms which recur season after season with such regularity that it cannot be doubted but that they are in some way due to the position of the sun on, or near the equator. The anemological systems of the two hemispheres are so distinct, that the bodily transfer from one to the other of the large volumes of air which during several months creep after the sun—pressed in across the Line by the greater density of that in more distant parts of the earth, or drawn by the mere force of solar attraction, forming a species of annual atmospheric tide—may reasonably be supposed capable of producing well marked and even violent agitation.

Extending from the sun to the moon the deduction arrived at in the consideration of the equinoctial gales, Mr. Saxby has laid it down as a rule that a gale of wind, or some atmospheric disturbance may be expected whenever the moon crosses the equator, or turns back from her extreme north or south declination.* This is so far true that a large proportion of the storms which, in Europe, have been rendered famous by their disastrous violence have occurred at or about such a period; but on the other hand, these points of the lunation are so frequently passed by without any marked agitation of the air, and so many storms occur at other times, that the statement in its present form cannot be accepted as a scientific law. Mr. Saxby, however, claims for his so-called "Lunar Period," forty-eight hours on each side of the actual crossing or turning, and considers that any perturbation in the atmosphere during these four days satisfies the rule which he pro-

* S. M. SAXBY: Lunar Influence on Weather, 2nd Edit. p. 100, and *passim*.

poses: he loses sight of the fact that the whole interval between crossing and turning is only seven days; and that, even were such things regulated by mere chance, a gale would be more likely to happen on one of four days named than on one of three.

Although, therefore, it seems highly probable that, if the attraction of the sun and moon does produce the continuous atmospheric current round the earth, changes in the attraction, resulting from changes in their declination or in their relative position, must also produce corresponding changes in the direction or velocity of the current; still, as our observations are necessarily conducted near the surface of the earth, these changes are, for the most part, so masked by meteorological influences—differences of temperature, humidity, possibly of electricity—that it would be vain to endeavour to distinguish them.

That these meteorological influences are exceedingly powerful, cannot be doubted. They are capable of producing, and do produce, very marked effects, and must be carefully observed before we can form correct judgments of wind and weather in special localities. In these pages I have treated of them in the most general terms; and whilst explaining their mode of action, have wished rather to show in what particulars their effects have been misunderstood or exaggerated. My aim has been—not to write a treatise on Meteorology, but—to trace the connection between that science and Physical Geography, in a more close and exact manner than has hitherto been done. I have endeavoured to point out that the graduation of *ordinary* meteorological differences—differences of specific gravity, whether in air or sea—is so extremely gentle, and at the same time so irregular, as to render it in the highest degree improbable that they alone can account for the very sensible phenomena observed; and that, as a matter of geographical fact, they do not account for them. Such

forces are not the first cause of the motion, of the currents continually streaming whether in the sea or in the air. But it is familiar to our every day observation that a body in rapid motion is more easily deflected from its course than a body that is moving slowly; that a body in motion at all is more easily made to move in an oblique direction than a body at rest. The author of "The Cricket Field" taught us, years ago, that "a slow ball must be played; it will not play itself." It is the same with other things. A volume of air or of water, at rest, requires a distinct force to move it: but when it is in motion, the direction of that motion may be altered, or the velocity may be increased by a force utterly inadequate to give it such a motion in the first instance.

I have endeavoured to trace the action of these different forces; to estimate, in some degree, the influence of each, and more especially of the geographical distribution of sea and land, of mountain and of plain, of fertile field and arid desert: and if, putting meteorological questions of local interest entirely on one side, I have thrown any useful light on the system of circulation continually going on in the atmosphere and in the ocean, as considered from a general point of view, I have attained the end towards which I have striven.

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